Initial Test Results and Test Plan for Differential Temperature Controllers Used in Solar Energy Systems

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Center for Building Technology
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
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PREFACE

SOLAR BUILDINGS RESEARCH AND DEVELOPMENT PROGRAM

In keeping with the national energy policy goal of fostering an adequate supply of energy at a reasonable cost, the United States Department of Energy (DOE) supports a variety of programs to promote a balanced and mixed energy resource system. The mission of the DOE Solar Buildings Research and Development Program is to support this goal, by providing for the development of solar technology alternatives for the buildings sector. It is the goal of the Program to establish a proven technology base to allow industry to develop solar products and designs for buildings which are economically competitive and can contribute significantly to building energy supplies nationally. Toward this end, the program sponsors research activities related to increasing the efficiency, reducing the cost, and improving the long term durability of passive and active solar systems for building water and space heating, cooling, and daylighting applications. These activities are conducted in four major areas: Advanced Passive Solar Materials Research, Collector Technology Research, Cooling Systems Research, and Systems Analysis and Applications Research.

The research effort which is described herein falls under Systems Analysis and Applications Research; an area which encompasses experimental testing, analysis, and evaluation of solar heating, cooling, and daylighting systems for residential and non-residential buildings. Specifically, this report documents the initial efforts in developing test procedures for determining the functional performance of differential controllers used in solar energy systems in order to mitigate solar control system reliability problems which have been identified as a major source of failure. It in anticipated that these procedures will serve as a starting point in the development of a rational consensus standard for solar controllers.

DISCLAIMER

This report is intended to be an initial effort in developing test procedures for determining the functional performance of differential temperature controllers used in solar energy systems. As such, the controllers tested were used to evaluate the adequacy and completeness of the test procedures under development and not to judge the performance of the controllers tested for any specific application. Although the units tested were not identified by manufacturer, inclusion of a given unit in this report in no case implies a recommendation or endorsement by the National Bureau of Standards, and the presentation should not be construed as a certification that any unit would provide the indicated performance. Similarly, the omission of a unit does not imply that its capabilities are more or less than those of the included units.

ACKNOWLEDGEMENTS

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I INTRODUCTION

From the inception of the Department of Energy (DOE) active solar heating and cooling program, control system reliability problems have been identified as a major source of failure. Although the sensor elements of the control systems have contributed to a number of these failures and operational problems [1], recent reports by the Solar Energy Research Institute (SERI) [2, 3] include extensive literature reviews that indicate the controllers themselves are a source of failure. Another SERI report [4] covering the results of a detailed survey of 122 operational residential solar water heater systems concludes: "Differential Controllers were responsible for the largest number of failures that resulted in repair cost in excess of $50 to the home owner." In addition, the results of tests conducted on controllers by SERI [3] concludes: "These tests reveal current problems with ... controller accuracy, heat and humidity effects, long-term electronics, failure to meet specifications, poor instructions, and incorrect color-coding of wires."

In a related effort under the DOE Systems Effectiveness Research Program, two meetings were held at the National Bureau of Standards (NBS) in August 1983 to develop research priorities for improving the effectiveness of active solar hot water and space conditioning systems. The meetings were attended by solar industry representatives (manufacturers, contractors, architects and engineers) as well as government representatives. The recommended research priorities developed by this group was documented in a recently published NBS report [5] and cited control systems as the highest ranked research area that is appropriate for Federal Government support. Included in the solar controls research area is a recommended objective for

a DOE-sponsored controls research program including the development of standard test methods and evaluation procedures for assessing the performance of controller hardware and controller interfaces. Specifically, the report states: "These [SERI] tests are important to the controller manufacturers. However, the tests should be expanded to include more controller types and additional environmental conditions. A review committee, comprised of manufacturers and DOE/SERI/NBS personnel, should be formed to provide advice regarding the tests to be performed."

In view of the above, this report documents the initial efforts in developing test procedures for determining the functional performance of differential temperature controllers used in solar energy systems. Included in this report is an overall test plan outline that has been sent to individuals at Government laboratories, controller manufacturers, and others having interests in differential temperature controllers. The overall test plan incorporating comments received is included in the Appendix. In addition, the body of this report contains the results of an initial effort to develop test procedures to evaluate the functional characteristics and controller response to line voltage fluctuation at normal room ambient conditions for non-adjustable controllers. For each test, the purpose is stated and the test condition, procedures, results, and conclusions detailed.

It is anticipated that these test procedures will serve as a starting point in the development of a rational consensus standard for solar controllers.

II. SCOPE OF CONTROLLER TESTS

General

The overall planning for the test procedure development for differential temperature controllers envisioned the testing of a broad range of controllers procured from a number of sources. One end of this broad spectrum included the most basic controllers of the non-display, non-adjustable type while the other end included those controllers equipped with a host of optional modes, displays, settings, etc. Because of funding limitations, the scope for this initial effort was confined to testing those units that could provide a solid, though limited test base, that later could be expanded. Consequently, the units selected were the basic non-adjustable, non-display type controllers although these units featured a limited number of adjustable options and other functions which were also evaluated.

Four units were selected for testing; three identical controllers procured from a single manufacturer and a single, similar type unit procured from a second source. The three units were chosen in order to assess whether the test procedures could characterize the performance differences between identical units from a single manufacturer with the single, similar unit chosen to assess the difference in performance between controllers procured from separate sources. Initially, tests were intended to be limited to only characterizing the controller's functional response under the nominal controller operating conditions of 70°F and the nominal power input of 115 VAC at 60 Hertz. Because the test fixture was designed with a feature that allowed the controller's input voltage to be easily adjusted, additional

tests were conducted to determine the controller's response to line voltage fluctuation.

Test Plan Implementation

The testing of differential temperature controllers described in this report is an initial step in implementing the overall test plan included in the Appendix. Although the overall test plan provides a comprehensive array of proposed tests covering all aspects of controller performance under a variety of environmental conditions, the tests described herein correspond specifically to the following tests outlined in the overall plan:

- FUNCTIONAL TESTS - (AMBIENT)
  - Non-adjustable Unit
    - delta T "ON"
    - delta T "OFF"
    - Storage High Temperature Limit
    - Recirculating Freeze Protection
    - Other Features
  - Adjustable Unit
    - Storage High Temperature Limit
    - Other Features
- SENSITIVITY TO LINE VOLTAGE FLUCTUATION - (AMBIENT)
  - Non-adjustable Unit
    - delta T "ON"
    - delta T "OFF"
    - Recirculating Freeze Protection

The three identical units procured from a single manufacturer included the optional feature for providing an auxiliary input for RECIRCULATING FREEZE PROTECTION. Separate tests were conducted to determine the controller's response under these conditions as an implicit requirement of the overall test plan. In addition, the single unit procured from a second source was provided with a PUMP "OFF" BELOW 80°F option. Although this is an uncommon controller option and was not identified specifically in the overall test plan, this feature was also tested and the results included in this report.

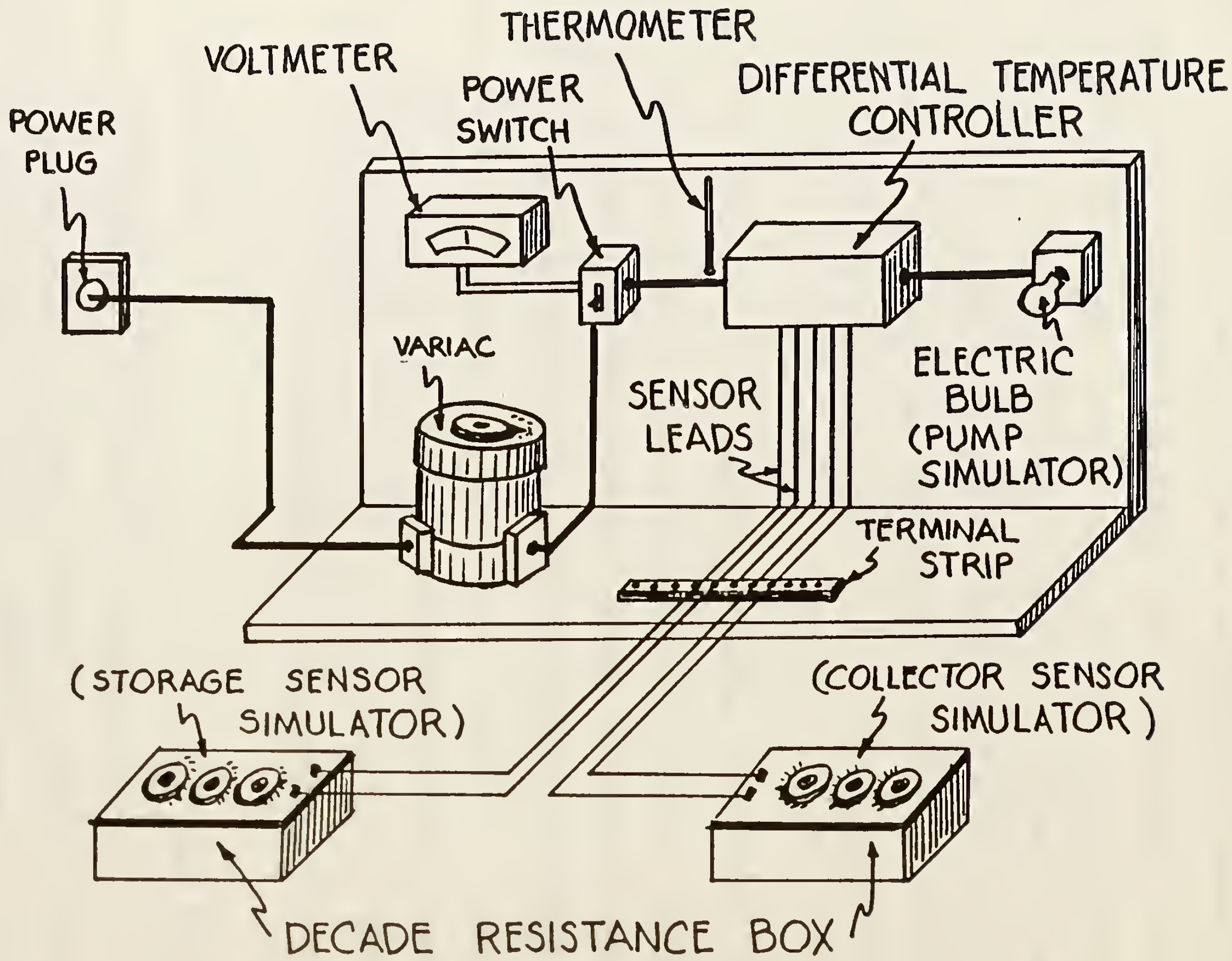
Additional tests were conducted to characterize the controller's response to the manufacturing tolerances associated with the sensor. These include CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF") and CONTROL RESPONSE TO SENSOR TOLERANCE (RECIRCULATING FREEZE PROTECTION). These tests are intended to reconcile the behavior of actual sensors installed in operating solar systems with the simulated sensors used to conduct the controller tests and to form a strong basis for interfacing sensor performance with controller performance.

<u>Test Fixture Used</u>

To facilitate controller testing, a test fixture was constructed as shown schematically in Figure 1. Power was obtained from an ordinary laboratory branch circuit electrical receptacle and fed through a variac and a power switch to the controller being tested. For testing under ambient voltage conditions, the variac was held at a constant 115 VAC at 60 Hertz with the parallel voltmeter confirming the input voltage. For tests conducted to determine the controller's SENSITIVITY TO LINE VOLTAGE FLUCTUATION, the variac was adjusted to provide the power input at the desired higher or

Figure 1

CONTROLLER TEST FIXTURE



lower voltage. For example, the variac was set and held at 90 VAC and later at 130 VAC for the voltage tests described later in this report. The controller's pump output was simulated by an electric light bulb which gave a very positive indication of controller relay activation. A thermometer indicated controller ambient temperature.

The differential temperature controller to be tested was wired as shown in Figure 1 following the manufacturer's instructions. A large amount of slack was left in the power wiring between the controller and both the power switch and electric bulb to facilitate the installation and removal of the controllers. The excess slack was placed in the back of the test fixture by threading it through holes drilled in the vertical board of the test fixture (not shown in Fig. 1). The sensor leads were connected to the controller as recommended by the manufacturer and fixed to a terminal strip on the test fixture. Generally, only four terminals are used; two for the storage sensor and two for the collector sensor. However, provision was made on the terminal strip to accommodate additional sensor leads since some controllers have operating options which require additional sensor inputs.

The controller temperature inputs were simulated using accurately calibrated decade resistance boxes. These resistances correspond to thermistor operating temperatures. A typical temperature/resistance table is shown in Figure 2. Although these decade boxes were used to simulate thermistor sensors, the most common type of sensor currently in use in solar applications, the test fixture can be used for different sensor types as well. For example, a decade resistance box can also be used to simulate

a resistance temperature detector (RTD) sensor and perhaps an accurate voltage source to simulate a thermocouple sensor.

The use of simulated temperature inputs to the controller greatly expedited the tests. Although the tests could conceptually be conducted using actual thermistors, the effort involved would be highly impractical considering the large number of test points involved. For example, if implemented for a delta T "ON" test, the actual storage thermistor would have to be placed in a temperature bath and stabilized to some fixed temperature. The collector sensor would be located in another temperature bath and the temperature of this bath slowly raised until the controller "ON" circuit is activated, and the bath actuating temperature accurately recorded. Because of measurement uncertainties, this very time consuming procedure may have to be repeated several times to get a representative reading just for one delta T "ON" point. The simulated sensor procedure for a delta T "ON" test, on the other hand, requires a known resistance to be set on the storage simulator decade resistance box and the knobs on the collector simulator decade resistance box turned until the delta T "ON" function is activated. The resistance is read and converted into a temperature. The controller triggering point using this method has proven to be very repeatable with each individual delta T "ON" measurement being accomplished in less than a minute.

Units Tested

For the initial tests, the differential temperature controllers selected were generally non-adjustable units with no display function. Some of the units, however, had certain adjustable features and these were also

Figure 2

TEMPERATURE/RESISTANCE TABLE
10,000 ohm THERMISTOR AT 77°F

°F	Ohms	°F	Ohms	°F	Ohms	F	Ohms
32.0	32660	78.0	9760	123.0	3526	168.0	1453
33.0	31748	79.0	9526	124.0	3453	169.0	1427
34.0	30864	80.0	9299	125.0	3381	170.0	1401
35.0	30008	81.0	9078	126.0	3311	171.0	1376
36.0	29178	82.0	8862	127.0	3243	172.0	1351
37.0	28375	83.0	8653	128.0	3176	173.0	1326
38.0	27596	84.0	8449	129.0	3111	174.0	1303
39.0	26840	85.0	8250	130.0	3048	175.0	1279
40.0	26109	86.0	8057	131.0	2986	176.0	1256
41.0	25400	87.0	7869	132.0	2925	177.0	1234
42.0	24711	88.0	7685	133.0	2866	178.0	1212
43.0	24045	89.0	7507	134.0	2808	179.0	1191
44.0	23399	90.0	7333	135.0	2751	180.0	1170
45.0	22771	91.0	7164	136.0	2696	181.0	1149
46.0	22162	92.0	6999	137.0	2642	182.0	1129
47.0	21572	93.0	6839	138.0	2589	183.0	1109
48.0	21000	94.0	6683	139.0	2538	184.0	1090
49.0	20444	95.0	6531	140.0	2488	185.0	1071
50.0	19906	96.0	6382	141.0	2438	186.0	1052
51.0	19382	97.0	6238	142.0	2390	187.0	1034
52.0	18875	98.0	6097	143.0	2343	188.0	1016
53.0	18382	99.0	5960	144.0	2297	189.0	999
54.0	17904	100.0	5827	145.0	2253	190.0	982
55.0	17440	101.0	5696	146.0	2209	191.0	965
56.0	16990	102.0	5570	147.0	2166	192.0	948
57.0	16552	103.0	5446	148.0	2124	193.0	932
58.0	16127	104.0	5325	149.0	2083	194.0	916
59.0	15715	105.0	5208	150.0	2043	195.0	901
60.0	15314	106.0	5093	151.0	2003	196.0	886
61.0	14925	107.0	4981	152.0	1965	197.0	871
62.0	14547	108.0	4873	153.0	1928	198.0	856
63.0	14180	109.0	4767	154.0	1891	199.0	842
64.0	13823	110.0	4663	155.0	1855	200.0	828
65.0	13476	111.0	4562	156.0	1820	201.0	814
66.0	13139	112.0	4463	157.0	1786	202.0	800
67.0	12812	113.0	4367	158.0	1752	203.0	787
68.0	12494	114.0	4274	159.0	1719	204.0	774
69.0	12185	115.0	4182	160.0	1687	205.0	761
70.0	11884	116.0	4093	161.0	1656	206.0	749
71.0	11592	117.0	4006	162.0	1625	207.0	737
72.0	11308	118.0	3921	163.0	1595	208.0	725
73.0	11031	119.0	3838	164.0	1565	209.0	713
74.0	10763	120.0	3757	165.0	1536	210.0	701
75.0	10502	121.0	3678	166.0	1508	211.0	690
76.0	10248	122.0	3601	167.0	1481	212.0	697
77.0	10000						

evaluated as part of the test procedures. In total, four units were tested for functional evaluation and sensitivity to line voltage fluctuation. Three of the four units were identical models procured from a single manufacturer and the fourth controller, of a similar type, was procured from a second source.

The three identical units are designated units IA, IB, and IC throughout this report. They each have a fixed delta T "ON" of 20°F and a delta T "OFF" of 5°F (designated hereinafter as 20/5). As an option, the controller can be wired for recirculating freeze protection by either using the collector sensor as the freeze indicating element, or through the use of a separate freeze sensor. In the recirculating freeze protection mode, the indicating element would cause the circulating pump to be activated when the temperature falls to approximately 40°F and deactivated when the temperature rises to approximately 44°F. In addition, these differential temperature controllers have infinitely adjustable storage high temperature limits that can be set by rotating a trimpot knob on the circuit board to the desired setting between 105°F and 212°F. In operation, the circulating pump is deactivated when the storage tank temperature exceeds the high temperature limit setting. These controllers have a single relay output and operate at a nominal line voltage of 115 VAC at 60 Hertz. Also, no temperature display is provided.

The single controller procured from a second manufacturer is similar to the three identical units described above. The key distinguishing feature of this unit permits the user to change the controller differential temperature range by pressing a rocker switch located internally on the

printed circuit board. With the switch in one position, the delta T "ON" is fixed at 18°F and the delta T "OFF" fixed at 5°F (designated hereinafter as 18/5). With the switch in the other position, the delta T "ON" is fixed at 9°F and the delta T "OFF" fixed at 4°F (similarly designated hereafter as 9/4). Although a single unit, test sequences were conducted separately for the 18/5 mode and the 9/4 mode. These tests are designated throughout this report as IIa and IIb, respectively. This unit can be operated in the recirculating freeze protection mode only by using the collector sensor as the freeze indicator. (It should be noted that for both types of units, additional thermistors or "snap" switches are recommended for installation in the collector circuit for added freeze protection.) Other features of this unit allow for a printed circuit board switch setting of the storage high temperature limit to either OFF, 180°F, or 160°F and an option that provides PUMP "OFF" BELOW 80°F. When this option is selected by moving an internal switch, the pump will not turn on when the collector sensor temperature is below 80°F. This feature prevents water circulation at night after a large amount of hot water has been consumed or when a reverse thermosyphon effect would normally cause the pump to turn on. Enabling the recirculating freeze protection mode, however, overrides this option. This controller also has a single relay output, operates at a nominal line voltage of 115 VAC at 60 Hertz, and has no temperature display.

The features describe above for the units tested are tabulated in Figure 3.

Figure 3

SUMMARY OF CONTROLLER FEATURES FOR UNITS TESTED

Unit	On	Off	Freeze Protection	Storage High Limit	Display	Other Feature	Output	Input Power
IA IB IC (3 Units)	Fixed 20°F	Fixed 5°F	(1) Recirculating On 40°F Off 44°F	Adjustable (2) 205°F to 212°F	None	None	Single Relay	117 VAC ±10% 60 Hz
IIa	Fixed 18°F	Fixed 5°F	Recirculating Using Collector Sensor	Off or 180°F or 160°F (4)	None	Off Below 80°F (5)	Single Relay	115 VAC ±15% 60 Hz
	or (4)							
IIb (1 Unit)	Fixed 9°F	Fixed 4°F						

(1) 2 Modes Available - Collector Sensor or Separate Freeze Sensor
(2) Rotatable Potentiometer
(3) 212°F Setting Defeats High Limit
(4) Switch Selectable
(5) Freeze Protection Enabling Switch Overrides this Function

III TEST PROCEDURE DEVELOPMENT

General

This section documents the specific tests conducted on the differential temperature controllers described in Section II. The following is included for each test: (1) the purpose of the test; (2) the test conditions and other detailed information concerning the tests or the units tested; (3) the test procedures used; (4) the test results; and (5) the conclusions reached concerning the adequacy of the procedure used. Shown below is a complete listing of all tests conducted.

TEST NO.	NAME	UNIT
	FUNCTIONAL TESTS - (AMBIENT)	
1	BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")	IA; IB; IC; IIa,IIb
2	RECIRCULATING FREEZE PROTECTION	IA; IB; IC; IIa,IIb
3	CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")	IA; IB; IC; IIa,IIb
4	CONTROLLER RESPONSE TO SENSOR TOLERANCE (RECIRCULATING FREEZE PROTECTION)	IA; IB; IC; IIa,IIb
5	STORAGE HIGH TEMPERATURE LIMIT	IA; IB; IC; IIa,IIb
6	RECIRCULATING FREEZE PROTECTION USING AUXILIARY SENSOR	IA; IB; IC
7	PUMP "OFF" BELOW 80°F	IIa,IIb
	SENSITIVITY TO LINE VOLTAGE FLUCTUATION - (AMBIENT)	
8	CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")	IA; IB; IC; IIa,IIb
9	CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION)	IA; IB; IC; IIa,IIb

Although the tests were performed using simulated thermistor input to the controller and the test procedures written for simulated thermistor input,

with little modification the procedures would apply to other types of sensor inputs. Although the test procedures indicated result from the testing of units that are largely of the non-adjustable, non-display type, with some minor modification the test procedures are probably valid for units with adjustable options and display features as well. This should be confirmed, however, through actual testing of such units. In addition, the data collected during these tests will form the basis for evaluating the controller when data from tests run at extreme ambient conditions are compared and analyzed.

FUNCTIONAL TESTS-(AMBIENT)

THE FOLLOWING TESTS WERE CONDUCTED TO EVALUATE THE CONTROLLER'S FUNCTIONAL CHARACTERISTICS. THE TESTS WERE CONDUCTED AT AMBIENT CONDITIONS OF APPROXIMATELY 70°F WITH POWER SUPPLIED AT 115 VAC AT 60 HERTZ.

TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

Purpose

This test is intended to serve as a baseline to characterize the overall delta T "ON" and "OFF" response of the differential temperature controller over a broad range of input signals and as a reference for analyzing other test results.

Test Conditions

This test is performed using the nominal temperature/resistance table for the sensors provided or recommended for use with the controller. (This table is shown in Figure 2.) Delta T "ON" and "OFF" tests are conducted at 5°F intervals over the expected operating range using resistance decade

boxes to simulate operating temperatures. The tests are performed at ambient conditions and with power being supplied at nominal line voltage. Other functional features such as STORAGE HIGH TEMPERATURE LIMIT, PUMP "OFF" BELOW 80°F, etc. are generally switched off, not connected, or otherwise made inoperable. (Tests of these features are described in subsequent sections of this report.)

Specifically, for the three identical units tested (IA, IB, and IC), the adjustable STORAGE HIGH TEMPERATURE LIMIT was set to "OFF" and the single fixed delta T "ON" and "OFF" (20/5) tested as described below. For the other unit tested, both the adjustable STORAGE HIGH TEMPERATURE LIMIT and the PUMP "OFF" BELOW 80°F features were switched to "OFF". Because the unit contains a switch selectable option for operating at 18/5 or 9/4, separate delta T "ON" and "OFF" tests were run at each setting (Tests IIa and IIb). Tests on all units were conducted at a room ambient of approximately 70°F* and an input voltage of 115 VAC at 60 Hertz.

In addition, baseline tests for all units were conducted with the storage simulator fixed and the collector simulator varied until the tested switching function was activated or deactivated. The tests were conducted with the simulated storage sensor set at 60°F and raised in increments of 5°F until the upper limit of 210°F was reached. These values were selected since water inlet temperatures generally do not range much lower than 60°F and storage temperatures are rarely allowed to reach boiling temperatures.

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* All temperatures in this report are expressed in degrees Fahrenheit as it is common practice in the solar controller industry to generally use English units for temperature/resistance tables, delta T values, and physical controller markings and settings.

The test results were found to be consistently repeatable (±2 ohms) and, consequently, each delta T "ON" and "OFF" test was conducted only once.

<u>Procedure</u>

1. All tests are conducted using the nominal temperature/resistance table provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Set the storage and collector sensor simulated temperatures (resistance) to correspond to the lowest storage temperature to be tested.
3. Increase the collector sensor simulated temperature (by decreasing the resistance) until the pump output is activated and record the resistance corresponding to the delta T "ON" temperature.
4. Decrease the collector sensor simulated temperature (by increasing the resistance) until the pump output is deactivated and record the resistance corresponding to the delta T "OFF" temperature.
5. Repeat step 2 after increasing the simulated storage temperature by 5°F (by decreasing the resistance).
6. Repeat steps 3 and 4.
7. Continue this procedure until the storage and collector simulated temperatures (resistance) correspond to the highest temperature to be tested.
8. Convert the recorded resistances to operating temperatures using the nominal temperature/resistance table appropriate for the simulated sensor.

9. Controllers designed with the option to select more than a single fixed delta T "ON" and "OFF" shall be tested separately at each discrete switch setting.

Results

The delta T "ON" and "OFF" response for the three identical units tested are shown for Units IA, IB, and IC in Tables 1, 2, and 3, respectively. The manufacturer's literature for these controllers specify a controller delta T "ON" accuracy of 20°±2.5°F. As can be seen, the tests indicated all controllers operated within the specification over an operating range of 60° through 210°F with the exception of controller IB which was activated at a delta T "ON" of 17.2°F when the storage temperature was fixed at 60°F. All three of the controllers (IA, IB, and IC) were seen to operate out of manufacturer's delta T "OFF" specification (5° ± 2.5°F) at the high storage temperature settings.

The delta T "ON" and "OFF" response for the second unit tested is shown in Table 4 and 5. Table 4 represents the response when the unit is set in the 18/5 mode (IIa) and Table 5 for the 9/4 setting (IIb). Since no accuracy range was specified for this unit, for purposes of this report the accuracy specified for the first three units tested (IA, IB, and IC) was used. Under this assumed accuracy condition, it is noted that the unit procured from the second manufacturer operated within the tolerance indicated for both settings (IIa and IIb) in the delta T "ON" and "OFF" mode over the entire range tested.

TABLE 1

BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

UNIT IA

Storage Temp Setting	Delta T ON				Delta T OFF			
	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
60	77.8		17.8		65.8		5.8	
65	83.0		18.0		70.9		5.9	
70	88.2		18.2		75.9		5.9	
75	93.4		18.4		80.9		5.9	
80	98.8		18.8		85.9		5.9	
85	104.0		19.0		90.8		5.8	
90	109.3		19.3		95.7		5.7	
95	114.5		19.5		101.0		6.0	
100	119.8		19.8		106.0		6.0	
105	125.0		20.0		111.0		6.0	
110	130.3		20.3		116.0		6.0	
115	135.5		20.5		121.0		6.0	
120	140.7		20.7		126.0		6.0	
125	145.9		20.9		130.9		5.9	
130	151.0		21.0		135.8		5.8	
135	156.2		21.2		140.8		5.8	
140	161.2		21.2		145.7		5.7	
145	166.2		21.2		150.5		5.5	
150	171.2		21.2		155.3		5.3	
155	176.6		21.6		160.2		5.2	
160	181.6		21.6		164.9		4.9	
165	186.7		21.6		169.5		4.5	
170	191.6		21.6		174.2		4.2	
175	196.6		21.6		179.1		4.1	
180	201.5		21.5		183.6		3.6	
185	206.5		21.5		188.3		3.3	
190	211.5		21.5		192.9		2.9	
195	216.4		21.4		197.5		2.5	
200	221.2		21.2		202.0	2.0		
205	226.1		21.1		206.6	1.6		
210	230.8		20.8		211.0	1.0		

*Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 2

BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

UNIT IB

Storage Temp Setting	Delta T ON				Delta T OFF			
	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
60	77.2	17.2			65.4		5.4	
65	82.4		17.5		70.4		5.4	
70	87.7		17.7		75.5		5.5	
75	92.8		17.8		80.5		5.5	
80	98.2		18.2		85.4		5.4	
85	103.4		18.4		90.4		5.4	
90	108.6		18.6		95.3		5.3	
95	113.9		18.9		100.6		5.6	
100	119.1		19.1		105.5		5.5	
105	124.4		19.4		110.5		5.5	
110	129.6		19.6		115.5		5.5	
115	134.8		19.8		120.5		5.5	
120	140.0		20.0		125.5		5.5	
125	145.2		20.2		130.4		5.4	
130	150.3		20.3		135.3		5.3	
135	155.5		20.5		140.3		5.3	
140	160.5		20.5		145.2		5.2	
145	165.5		20.5		150.0		5.0	
150	170.5		20.5		154.8		4.8	
155	175.5		20.5		159.7		4.7	
160	180.9		20.9		164.4		4.4	
165	185.9		20.9		169.0		4.0	
170	190.8		20.8		173.6		3.6	
175	195.8		20.8		178.6		3.6	
180	200.7		20.7		183.1		3.1	
185	205.7		20.7		187.8		2.7	
190	210.7		20.7		192.4	2.4		
195	215.6		20.6		196.9	1.9		
200	220.4		20.4		201.4	1.4		
205	225.1		20.1		206.0	1.0		
210	230.0		20.0		210.4	0.4		

*Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 3

BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

UNIT IC

Storage Temp Setting	Delta T ON				Delta T OFF			
	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
60	77.8		17.8		65.9		5.9	
65	83.1		18.1		70.9		5.9	
70	88.3		18.3		76.0		6.0	
75	93.5		18.5		81.0		6.0	
80	98.9		18.9		86.0		6.0	
85	104.1		19.1		90.9		5.9	
90	109.3		19.3		95.8		5.8	
95	114.6		19.6		101.1		6.1	
100	119.8		19.8		106.1		6.1	
105	125.1		20.1		111.1		6.1	
110	130.3		20.3		116.1		6.1	
115	135.6		20.6		121.1		6.1	
120	140.8		20.8		126.1		6.1	
125	146.0		21.0		131.0		6.0	
130	151.1		21.1		136.0		6.0	
135	156.3		21.3		140.9		5.9	
140	161.3		21.3		145.8		5.8	
145	166.3		21.3		150.6		5.6	
150	171.3		21.3		155.4		5.4	
155	176.7		21.7		160.3		5.3	
160	181.7		21.7		165.0		5.0	
165	186.7		21.7		169.7		4.7	
170	191.7		21.7		174.3		4.3	
175	196.7		21.7		179.2		4.2	
180	201.7		21.7		183.8		3.8	
185	206.7		21.7		188.4		3.4	
190	211.7		21.7		193.1		3.1	
195	216.6		21.6		197.6		2.6	
200	221.4		21.4		202.2	2.2		
205	226.2		21.2		206.7	1.7		
210	230.9		20.9		211.1	1.1		

*Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 4

BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

UNIT IIa

Storage Temp Setting	Delta T ON				Delta T OFF			
	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
60	75.8		15.8		65.9		5.9	
65	80.1		15.9		70.9		5.9	
70	86.0		16.0		75.9		5.9	
75	91.1		16.1		80.9		5.9	
80	96.4		16.4		85.9		5.9	
85	101.5		16.5		90.8		5.8	
90	106.5		16.5		95.7		5.7	
95	111.6		16.6		100.9		5.9	
100	116.8		16.8		105.9		5.9	
105	121.9		16.9		110.8		5.8	
110	127.0		17.0		115.8		5.8	
115	132.2		17.2		120.9		5.9	
120	137.4		17.4		126.1		6.1	
125	142.6		17.6		131.2		6.2	
130	147.8		17.8		136.2		6.2	
135	153.0		18.0		141.3		6.3	
140	158.1		18.1		146.4		6.4	
145	163.1		18.1		151.4		6.4	
150	168.2		18.2		156.5		6.5	
155	173.2		18.2		161.5		6.5	
160	178.6		18.6		166.5		6.5	
165	183.6		18.6		171.5		6.5	
170	188.7		18.7		176.7		6.7	
175	193.8		18.8		181.7		6.7	
180	198.8		18.8		186.7		6.7	
185	203.9		18.9		191.7		6.7	
190	209.0		19.0		196.9		6.9	
195	214.0		19.0		202.0		7.0	
200	219.0		19.0		207.1		7.1	
205	224.1		19.1		212.2		7.2	
210	229.0		19.0		217.3		7.3	

* Delta T ON 18°F
Delta T OFF 5°F
Accuracy not specified by manufacturer

TABLE 5

BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

UNIT IIb

Storage Temp. Setting °F	Delta T ON				Delta T OFF			
	Collector Temp. °F	Outside Spec. (Low) <6.5°F	In Spec.* 9°F ±2.5°F	Outside Spec. (High) >11.5°F	Collector Temp. °F	Outside Spec. (Low) <1.5°F	In Spec.* 4°F ±2.5°F	Outside Spec. (High) >6.5°F
60	68.5		8.5		65.0		5.0	
65	73.5		8.5		70.0		5.0	
70	78.5		8.5		75.0		5.0	
75	83.5		8.5		80.0		5.0	
80	88.5		8.5		85.0		5.0	
85	93.4		8.4		89.9		4.9	
90	98.6		8.6		94.8		4.8	
95	103.6		8.6		100.0		5.0	
100	108.5		8.5		104.9		4.9	
105	113.5		8.5		109.9		4.9	
110	118.6		8.6		114.9		4.9	
115	123.7		8.7		120.0		5.0	
120	128.7		8.7		125.0		5.0	
125	133.8		8.8		130.1		5.1	
130	138.9		8.9		135.2		5.2	
135	143.9		8.9		140.3		5.3	
140	149.0		9.0		145.4		5.4	
145	153.9		8.9		150.4		5.4	
150	158.9		8.9		155.4		5.4	
155	163.9		8.9		160.4		5.4	
160	168.8		8.8		165.4		5.4	
165	173.6		8.6		170.3		5.3	
170	178.9		8.9		175.3		5.3	
175	183.7		8.7		180.6		5.6	
180	188.6		8.6		185.6		5.6	
185	193.5		8.5		190.7		5.7	
190	198.5		8.5		195.7		5.7	
195	203.3		8.3		200.8		5.8	
200	208.2		8.2		205.8		5.8	
205	213.2		8.2		211.0		6.0	
210	218.0		8.0		216.1		6.1	

* Delta T ON 9°F
Delta T OFF 4°F
Accuracy not specified by manufacturer

Conclusions

From the above, it appears that the test procedure indicated does characterize the delta T "ON" and "OFF" response at ambient and nominal line voltage conditions. Further, given a controller operating tolerance, the unit can be evaluated with respect to its adherence to the specifications provided or assumed.

TEST 2 - RECIRCULATING FREEZE PROTECTION

Purpose

This test is intended to evaluate the controller's ability to provide recirculating freeze protection if provided as a controller feature or option.

Test Conditions

For convenience, this test is performed in conjunction with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") although it may be performed separately. This test is conducted to simulate conditions of falling outside temperatures, as determined by the collector sensor, and to establish the temperature at which the circulating pump will be activated to provides fluid recirculation in the collector loop to prevent freezing. When the outside temperature rises and no longer presents a freeze threat, the temperature which deactivates the circulating pump is also determined. These pump activation and deactivation points (controlled by the collector sensor) are measured at varying storage settings and use simulated temperature inputs (resistances) as established by the appropriate sensor temperature/resistance table.

Since each test is conducted at a fixed storage temperature, it is convenient to collect the recirculating freeze data in conjunction with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") which is also conducted at fixed storage temperatures. In effect, after the simulated collector temperature is lowered to determine the delta T "OFF" condition, the simulated collector temperature is then lowered further until the recirculating freeze protection activates the pump and the activating resistance is noted and recorded. The simulated collector temperature is then raised until the pump output is again deactivated.

Data points were taken with fixed storage temperature increments of 5°F in the range between 60°F and 210°F corresponding to the points used for TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF"). Because of the small changes noted in the recirculating freeze protection activation and deactivation temperatures (see Tables 6 through 10), data taken at 20°F storage temperature increments over the entire range would have been adequate. All tests are performed at ambient conditions with power being supplied at nominal line voltage.

It should be noted that the tests conducted above used the collector sensor as the input to the controller freeze protection function. As described earlier (see SECTION II), the three identical units (IA, IB, and IC) also had provision for freeze protection activation using an auxiliary sensor. (This feature was not provided in unit IIa and IIb.) The test procedure for this additional feature is described under TEST 6 - RECIRCULATING FREEZE PROTECTION USING AUXILIARY SENSOR.

Procedure

1. All tests are conducted using the nominal temperature/resistance table provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Set the storage and collector sensor simulated temperatures (resistance) to correspond to the lowest storage temperature used in conducting TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF").
3. Decrease the collector simulated temperature (by increasing the resistance) until the pump output is activated and record the resistance corresponding to the recirculating freeze protection "ON" temperature.
4. Increase the collector sensor simulator (by decreasing the resistance) until the pump output is deactivated and record the resistance corresponding to the recirculating freeze protection "OFF" temperature.
5. Repeat step 2 after increasing the simulated storage temperature by 20°F (by decreasing the resistance).
6. Repeat steps 3 and 4.
7. Continue this procedure over the storage temperature range used in conducting TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF").
8. Convert the recorded resistances to operating temperatures using the nominal temperature/resistance table appropriate for the simulated sensor.
9. This test may be conducted in conjunction with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") by continuing to lower the simulated collector temperature (after the delta T "OFF" deactivates the circulating pump) until the simulated temperature is reached where

the circulating pump output is again activated by the recirculating freeze protection circuit. The simulated temperature is again raised (by decreasing the resistance) until the recirculating freeze protection is deactivated as described in step 4. Although TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") is conducted at 5°F storage temperature setting intervals, data for TEST 2 - RECIRCULATING FREEZE PROTECTION generally need not be taken at intervals less than 20°F.

Results

The results of the recirculating freeze protection tests conducted on three identical units from a single manufacturer (Units IA, IB, and IC) are shown in Tables 6, 7, and 8 respectively. The recirculating freeze protection tests conducted on the single unit procured from a second manufacturer were conducted once with the unit in the 18/5 mode and a second time with the unit set in the 9/4 mode. These are indicated as tests IIa and IIb, respectively, and the results shown in Tables 9 and 10.

For Units IA, IB, and IC, the manufacturer's specifications indicated a freeze protection "ON" value of 40° ± 2°F and a freeze protection "OFF" value of 44° ± 2°F. As can be noted from Tables 6, 7, and 8, all three units provided recirculating freeze protection "ON" within specification and were out-of-specification on the high side for the recirculating freeze protection "OFF" function. The unit procured from the second manufacturer fell within the ranges indicated in the IIa mode and was out-of-specification in the IIb mode for the higher storage temperature settings. However, the tolerance range specified by this manufacturer was unclear and

Table 6

RECIRCULATING FREEZE PROTECTION* - UNIT IA

Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
60		40.5				54.1
65		40.4				53.9
70		40.3				53.7
75		40.3				53.5
80		40.3				53.3
85		40.3				53.2
90		40.3				52.9
95		40.3				52.7
100		40.3				52.5
105		40.3				52.3
110		40.3				52.1
115		40.2				51.8
120		40.2				51.6
125		40.2				51.4
130		40.2				51.2
135		40.2				51.0
140		40.2				50.8
145		40.2				50.6
150		40.2				50.4
155		40.2				50.2
160		40.2				50.1
165		40.2				49.9
170		40.2				49.7
175		40.2				49.6
180		40.2				49.5
185		40.2				49.3
190		40.2				49.2
195		40.2				49.1
200		40.2				49.0
205		40.2				48.9
210		40.2				48.8

* Test run concurrently with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 7

RECIRCULATING FREEZE PROTECTION* - UNIT IB

Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
60		39.9				50.2
65		39.9				49.3
70		39.9				49.3
75		39.9				49.0
80		39.9				48.7
85		39.9				48.4
90		39.9				48.3
95		39.9				48.1
100		39.9				47.9
105		39.9				47.8
110		39.9				47.6
115		39.8				47.5
120		39.8				47.4
125		39.8				47.3
130		39.8				47.3
135		39.8				47.2
140		39.8				47.1
145		39.8				47.1
150		39.8				47.1
155		39.8				47.1
160		39.8				46.9
165		39.8				46.9
170		39.8				46.9
175		39.8				46.8
180		39.8				46.8
185		39.8				46.8
190		39.8				46.8
195		39.8				46.8
200		39.8				46.7
205		39.8				46.7
210		39.8				46.7

* Test run concurrently with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 8

RECIRCULATING FREEZE PROTECTION* - UNIT IC

Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
60		39.8				50.2
65		39.8				49.8
70		39.8				49.4
75		39.8				49.1
80		39.8				48.8
85		39.8				48.5
90		39.8				48.3
95		39.7				48.1
100		39.7				47.9
105		39.7				47.8
110		39.7				47.7
115		39.7				47.6
120		39.7				47.4
125		39.7				47.4
130		39.7				47.3
135		39.7				47.2
140		39.7				47.1
145		39.7				47.1
150		39.7				47.1
155		39.7				47.0
160		39.7				46.9
165		39.7				46.9
170		39.7				46.9
175		39.7				46.8
180		39.7				46.8
185		39.7				46.8
190		39.7				46.8
195		39.7				46.8
200		39.7				46.7
205		39.7				46.7
210		39.7				46.7

* Test run concurrently with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 9

RECIRCULATING FREEZE PROTECTION* - UNIT IIa

Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
60		41.7			45.8	
65		41.7			45.7	
70		49.8			45.5	
75		41.8			45.5	
80		41.8			45.4	
85		41.9			45.3	
90		41.9			45.3	
95		41.9			45.2	
100		41.9			45.2	
105		42.0			45.1	
110		42.0			45.1	
115		42.0			45.1	
120		42.0			45.0	
125		42.0			45.0	
130		42.0			45.0	
135		42.0			44.9	
140		42.0			44.9	
145		42.0			44.9	
150		42.0			44.9	
155		42.0			44.9	
160		42.0			44.9	
165		42.0			44.9	
170		42.0			44.9	
175		42.0			44.9	
180		42.0			44.9	
185		42.0			44.9	
190		42.0			44.9	
195		42.0			44.9	
200		42.0			44.8	
205		42.0			44.8	
210		42.0			44.8	

* Test run concurrently with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

Table 10

RECIRCULATING FREEZE PROTECTION* - UNIT IIb

Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
60		41.7			45.7	
65		41.7			45.6	
70		41.8			45.5	
75		41.8			45.5	
80		41.8			45.4	
85		41.9			45.3	
90		41.9			45.2	
95		41.9			45.2	
100		41.9			45.1	
105		42.0			45.1	
110		42.0			45.1	
115		42.0			45.0	
120		42.0			45.0	
125		42.0			45.0	
130		42.0			45.0	
135		42.0			44.9	
140		42.0			44.9	
145		42.0			44.9	
150		42.0			44.9	
155		42.0			44.9	
160		42.0			44.9	
165			42.1		44.9	
170			42.1		44.9	
175			42.1		44.9	
180			42.1		44.9	
185			42.1		44.9	
190			42.1		44.9	
195			42.1		44.8	
200			42.1		44.8	
205			42.1		44.8	
210			42.1		44.8	

* Test run concurrently with TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

for purposes of this report, are assumed to be the same as for units IA, IB, and IC.

Conclusions

From the above it appears that the test procedures adequately indicate the response of the controller to recirculating freeze protection inputs over the operating range of the controller. However, for units without definitive specifications from the manufacturer, no statement can be made regarding the verification of the manufacturer's claims regarding this feature.

TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")

Purpose

This test is intended to evaluate the controller's delta T "ON" and "OFF" response to the tolerance extremes characteristic of the sensor types specified for use with the controller.

Test Conditions

Tests directly using the nominal temperature/resistance table values provided by the sensor manufacturer have been described under TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF"). These tests were conducted as if every sensor provided by the manufacturer exactly exhibited these temperature/resistance characteristics. In reality, the sensor tolerances may be ±0.5°F; ±1.0°F; some other values, or unspecified.

For the controllers tested, a review of the literature provided with each controller or obtained separately from the controller manufacturer showed that the nominal temperature/resistance table specified for the designated

sensors were all equivalent. However, the manufacturer of the three identical units tested (IA, IB, and IC) provided no sensor tolerances and the sensor specifications for the second type unit tested (IIa, IIb) were inconsistent in that a tolerance of ±0.5 °F was specified in one piece of information literature and a tolerance of ±0.6 °F in another. (It should be noted that as an adjunct activity, informal orientation tests conducted on ten identical sensors shipped with the controllers used for the tests described in this report exhibited a temperature tolerance spread greater than ±1.0 °F. The data for these tests are not included in this report).

Sensor tolerance tests are important in fully understanding the controller's response in an operational environment. By installing sensors with a tolerance of ±0.5 °F in a solar system, the controller would respond differently from the nominal response characterized under TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") if a high reading sensor (nominal +0.5 °F) were used as the collector sensor and a low reading sensor (nominal -0.5 °F) used as the storage sensor. A different response would also be expected if these sensors were reversed in the system; i.e., the high reading sensor (nominal +0.5 °F) used as the storage sensor and the low reading sensor (nominal -0.5 °F) as the collector sensor.

The tests to assess the controller's response to sensor tolerances were conducted by constructing a number of modified temperature/resistance tables based on the nominal temperature/resistance table provided. Since no consistent sensor tolerance data were indicated by the controller manufacturer, a tolerance of ±0.5 °F and a tolerance of ±1.0 °F was used for the modified tables. These assumed tolerance values were not important since the primary purpose of this test was to develop an assessment

Figure 4

MODIFIED TEMPERATURE/RESISTANCE TABLE
PARTIAL TABLE (32°F - 75°F)

Temp. °F	Nominal Minus 1.0°F	Nominal Minus 0.5°F	Nominal*	Nominal Plus 0.5°F	Nominal Plus 1.0°F
32	31748**	32205	32660	33115	---
33	30864	31307	31748	32204	32660
34	30008	30437	30864	31306	31748
35	29178	29594	30008	30436	30864
36	28375	28777	29178	29593	30008
37	27596	27986	28375	28776	29178
38	26840	27219	27596	27985	28375
39	26109	26475	26840	27218	27596
40	25400	25755	26109	26474	26840
41	24711	25056	25400	25754	26109
42	24045	24379	24711	25055	25400
43	23399	23723	24045	24378	24711
44	22771	23086	23399	23722	24045
45	22162	22467	22771	23085	23399
46	21572	21868	22162	22466	22771
47	21000	21287	21572	21867	22162
48	20444	20723	21000	21286	21572
49	19906	20176	20444	20722	21000
50	19382	19645	19906	20175	20444
51	18875	19129	19382	19644	19906
52	18382	18629	18875	19128	19382
53	17904	18144	18382	18628	18875
54	17440	17673	17904	18143	18382
55	16990	17216	17440	17672	17904
56	16552	16772	16990	17215	17440
57	16127	16340	16552	16771	16990
58	15715	15922	16127	16339	16552
59	15314	15515	15715	15921	16127
60	14925	15120	15314	15514	15715
61	14547	14737	14925	15119	15314
62	14180	14364	14547	14736	14925
63	13823	14002	14180	14363	14547
64	13476	13650	13823	14001	14180
65	13139	13308	13476	13649	13823
66	12812	12976	13139	13307	13476
67	12494	12654	12812	12975	13139
68	12185	12340	12494	12653	12812
69	11884	12035	12185	12339	12494
70	11592	11739	11884	12034	12185
71	11308	11451	11592	11738	11884
72	11031	11170	11308	11450	11592
73	10763	10898	11031	11169	11308
74	10502	10633	10763	10897	11031
75	10248	10376	10502	10632	10763

* See Figure 2
** All values in ohms

methodology and was not to evaluate any specific controller. The resulting modified temperature/resistance table along with the nominal temperature/resistance values are shown in Fig. 4. The modified sensor resistance is shown for tolerances of +1.0°F, +0.5°F; -0.5°F, and -1.0°F.

The tests conducted were basically the same tests described under TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") except the nominal temperature/resistance values were not used. Instead, the controller's response to the sensor tolerance was evaluated by using the appropriately modified temperature/resistance tables. The first tests assumed a sensor tolerance of ±0.5°F, with a high reading sensor (+0.5°F) providing the storage temperature input and a low reading sensor (-0.5°F) providing the collector temperature input. The high reading (+0.5°F) simulated storage temperature was taken from the +0.5°F modified temperature/resistance table and fixed as the storage input. After increasing the simulated collector temperature to the point where the delta T "ON" was activated, the resistance reading was converted to a delta T "ON" temperature using the -0.5°F modified temperature/resistance table. The simulated temperature resistance was decreased until a delta T "OFF" resisrance was recorded and converted to a delta T "OFF" temperature also using the -0.5°F modified temperature/resistance table. This test was then rerun using the low reading value (-0.5°F) from the modified temperature/resistance table as the fixed storage input. The delta T "ON" and "OFF" collector resistance reading were converted to corresponding temperatures by using the +0.5°F modified temperature resistance tables. The two tests were then repeated using the appropriately modified ±1.0°F temperature/resistance tables.

The tests were conducted at an ambient room temperature of approximately 70°F and at a nominal line voltage of 115 VAC at 60 Hertz. Data points taken at 20°F intervals starting at 60°F were deemed sufficient to characterize the CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF"), especially if analyzed in conjunction with the 5°F interval data used in establishing the controller's response in conducting TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF").

Procedure

1. Using both the nominal temperature/resistance table and the tolerance limits provided by the controller manufacturer for the sensors recommended for use with his controller, construct modified nominal-plus-tolerance and nominal-minus-tolerance temperature/resistance tables.
2. Follow the procedure detailed for TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") using the nominal-plus-tolerance table for the storage input resistance and the nominal-minus-tolerance table for the collector temperature output.
3. Repeat step 2 using the nominal-minus-tolerance table resistance for the storage input and the nominal-plus-tolerance table for the collector temperature output.
4. Repeat the tests described above after increasing the simulated storage temperature by 20°F increments instead of the 5°F increments specified under TEST 1 - BASELINE FUNCTIONAL TEST (DELTA "ON" AND "OFF").

Results

The results of the test for CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF") are shown in Tables 11 through 18. For units IA, IB, and IC, Table 11 indicates the test results with the simulated storage sensor set at nominal +0.5°F and the collector resistances converted to activation points (for both delta T "ON" or "OFF") at nominal -0.5°F. Table 12 represents the same data with the simulated storage sensor at nominal -0.5°F and the collector at nominal +0.5°F. Tables 13 and 14 are for conditions with simulated sensors at ±1.0°F tolerances. When comparing these results with the data from TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF"), Tables 1, 2, and 3, the degradation of controller response with increasing sensor tolerances becomes apparent. Where each of the units (IA, IB, IC) responded within the ±2.5°F controller specification in the delta T "ON" mode in the baseline test, the response was moderately out-of-specification for the ±0.5°F tolerance, and increasingly out-of-specification for the ±1.0°F tolerance. In the delta T "OFF" mode, each of the units (IA, IB, and IC) were out-of-specification for the baseline test at the high storage temperature settings (Tables 1, 2, and 3). For the condition where the storage simulator is set at nominal +1.0°F and the collector deactivation temperature determined at nominal -1.0°F (Table 13), the delta T "OFF" response is driven further out-of-specification with Unit IB exhibiting a negative response at a storage setting of 200°F. The significance of this negative response is that the solar unit would be dissipating heat instead of collecting heat under this set of conditions. In simulating a reversal of the ±1.0°F tolerance sensors (Fig. 14), for units IA, IB, and IC, the delta T "OFF" is out-of-specification on the high side in two units (IA and IC). This operational condition, over a broad

TABLE 11

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE +0.5°F/COLLECTOR - 0.5°F

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
	60	76.8	16.8			64.8		4.8	
	80	97.8		17.8		84.9		4.9	
	100	118.8		18.8		105.0		5.0	
IA	120	139.7		19.7		125.0		5.0	
20/5	140	160.3		20.3		144.7		4.7	
	160	180.6		20.6		164.0		4.0	
	180	200.6		20.6		182.8		2.8	
	200	220.0		20.0		201.1	1.1		
	60	76.3	16.3			64.4		4.4	
	80	97.2	17.2			84.5		4.5	
	100	118.1		18.1		104.6		4.6	
IB	120	139.0		19.0		124.5		4.5	
20/5	140	159.6		19.6		144.2		4.2	
	160	179.9		19.9		163.4		3.4	
	180	199.8		19.8		182.2	2.2		
	200	219.3		19.3		200.5	0.5		
	60	76.9	16.9			64.9		4.9	
	80	97.9		17.9		85.0		5.0	
	100	118.8		18.8		105.1		5.1	
IC	120	139.8		19.8		125.1		5.1	
20/5	140	160.4		20.4		144.8		4.8	
	160	180.8		20.8		164.1		4.1	
	180	200.7		20.7		183.0		3.0	
	200	220.2		20.2		201.3	1.3		

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 12

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE -0.5°F/COLLECTOR +0.5°F

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
	60	78.8		18.8		66.8		6.8	
	80	99.8		19.8		86.9		6.9	
	100	120.8		20.8		107.0		7.0	
IA	120	141.7		21.7		126.9		6.9	
20/5	140	162.2		22.2		146.6		6.6	
	160	182.6			22.6	165.8		5.8	
	180	202.5		22.5		184.6		4.6	
	200	221.7		21.7		202.8		2.8	
	60	78.3		18.3		66.4		6.4	
	80	99.3		19.3		86.5		6.5	
	100	120.2		20.2		106.5		6.5	
IB	120	141.0		21.0		126.5		6.5	
20/5	140	161.5		21.5		146.1		6.1	
	160	181.8		21.8		165.3		5.3	
	180	201.6		21.6		184.1		4.1	
	200	220.7		20.7		202.2	2.2		
	60	78.9		18.9		66.9		6.9	
	80	99.9		19.9		87.0		7.0	
	100	120.9		20.9		107.1		7.1	
IC	120	141.8		21.8		127.0		7.0	
20/5	140	162.3		22.3		146.7		6.7	
	160	182.7			22.7	166.0		6.0	
	180	202.1		22.1		184.8		4.8	
	200	221.8		21.8		203.0		3.0	

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 13

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE +1.0°F/COLLECTOR -1.0°F

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IA 20/5	60	75.8	15.8			63.8		3.8	
	80	97.0	17.0			83.9		3.9	
	100	117.9		17.9		104.2		4.2	
	120	139.9		18.9		124.2		4.2	
	140	159.4		19.4		143.9		3.9	
	160	179.7		19.7		163.1		3.1	
	180	199.5		19.5		181.8	1.8		
	200	218.7		18.7		200.0	0.0		
IB 20/5	60	75.2	15.2			63.4		3.4	
	80	96.4	16.4			83.5		3.5	
	100	117.3	17.3			103.8		3.8	
	120	138.2		18.2		123.7		3.7	
	140	158.7		18.7		143.4		3.4	
	160	178.9		18.9		162.6		2.6	
	180	198.7		18.7		181.2	1.2		
	200	218.0		18.0		199.5	-0.5		
IC 20/5	60	75.9	15.9			63.9		3.9	
	80	97.1	17.1			84.0		4.0	
	100	118.0		18.0		104.3		4.3	
	120	139.0		19.0		124.3		4.3	
	140	159.6		19.6		144.0		4.0	
	160	179.8		19.8		163.3		3.3	
	180	199.7		19.7		182.0	2.0		
	200	219.1		19.1		200.2	0.2		

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 14

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE -1.0°F/COLLECTOR +1.0°F

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
	60	79.9		19.9		67.9			7.9
	80	100.9		20.9		87.9			7.9
	100	121.8		21.8		108.0			8.0
IA	120	142.8			22.8	128.0			8.0
20/5	140	163.3			23.3	147.6			7.6
	160	183.6			23.6	166.8		6.8	
	180	203.5			23.5	185.6		5.6	
	200	222.8			22.8	203.8		3.8	
	60	79.3		19.3		67.4		7.4	
	80	100.3		20.3		87.5		7.5	
	100	121.2		21.2		107.5		7.5	
IB	120	142.1		22.1		127.5		7.5	
20/5	140	162.6			22.6	147.1		7.1	
	160	182.9			22.9	166.3		6.3	
	180	202.7			22.7	185.1		5.1	
	200	221.9		21.9		203.3		3.3	
	60	80.0		20.0		67.9			7.9
	80	100.9		20.9		88.0			8.0
	100	121.9		21.9		108.1			8.1
IC	120	142.9			22.9	128.1			8.1
20/5	140	163.4			23.4	147.8			7.8
	160	183.8			23.8	166.9		6.9	
	180	203.6			23.6	185.8		5.8	
	200	222.9			22.9	204.0		4.0	

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 15

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE +0.5°F/COLLECTOR -0.5°F

UNIT IIa

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IIa 18/5	60	74.8	14.8			64.9		4.9	
	80	95.1	15.1			85.0		5.0	
	100	115.7		15.7		104.9		4.9	
	120	136.4		16.4		125.1		5.1	
	140	157.1		17.1		145.4		5.4	
	160	177.6		17.6		165.5		5.5	
	180	197.9		17.9		185.9		5.9	
	200	217.8		17.8		206.1		6.1	

UNIT IIb

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	°F	<6.5°F	9°F ±2.5°F	>11.5°F	°F	<1.5°F	4°F ±2.5°F	>6.5°F
IIb 9/4	60	68.1		8.1		64.0		4.0	
	80	87.6		7.6		84.0		4.0	
	100	107.5		7.5		103.9		3.9	
	120	127.8		7.8		124.0		4.0	
	140	148.0		8.0		144.3		4.3	
	160	167.8		7.8		164.4		4.4	
	180	187.7		7.7		184.7		4.7	
	200	207.2		7.2		204.8		4.8	

* DELTA T ON 18°F/DELTA T OFF 5°F

** DELTA T ON 9°F/Delta T OFF 4°F
Accuracy not specified by manufacturer

TABLE 16

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE −0.5°F/COLLECTOR +0.5°F

UNIT IIa

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
	60	76.8		16.8		67.0		7.0	
	80	97.4		17.4		86.9		6.9	
	100	117.7		17.7		106.8		6.8	
IIa	120	138.5		18.5		127.0		7.0	
18/5	140	159.0		19.0		147.4		7.4	
	160	179.5		19.5		167.4		7.4	
	180	199.7		19.7		187.8			7.8
	200	219.5		19.5		207.9			7.9

UNIT IIb

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	°F	<6.5°F	9°F ±2.5°F	>11.5°F	°F	<1.5°F	4°F ±2.5°F	>6.5°F
	60	69.6		9.6		66.1		6.1	
	80	89.5		9.5		86.0		6.0	
	100	109.6		9.6		105.9		5.9	
IIb	120	129.8		9.8		126.0		6.0	
9/4	140	150.0		10.0		146.3		6.3	
	160	169.7		9.7		166.3		6.3	
	180	189.6		9.6		186.5		6.5	
	200	209.0		9.0		206.5		6.5	

* DELTA T ON 18°F/DELTA T OFF 5°F

** DELTA T ON 9°F/Delta T OFF 4°F
Accuracy not specified by manufacturer

TABLE 17

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE +1.0°F/COLLECTOR -1.0°F

UNIT IIa

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IIa 18/5	60	73.8	13.8			63.9		3.9	
	80	94.1	14.1			84.0		4.0	
	100	114.9	14.9			104.1		4.1	
	120	135.6		15.6		124.2		4.2	
	140	156.3		16.3		144.5		4.5	
	160	176.6		16.6		164.6		4.6	
	180	196.8		16.8		184.7		4.7	
	200	216.8		16.8		204.9		4.9	

UNIT IIb

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	°F	<6.5°F	9°F ±2.5°F	>11.5°F	°F	<1.5°F	4°F ±2.5°F	>6.5°F
IIb 9/4	60	66.5		6.5		63.1		3.1	
	80	86.6		6.6		83.1		3.1	
	100	106.8		6.8		103.2		3.2	
	120	127.0		7.0		123.2		3.2	
	140	147.1		7.1		143.5		3.5	
	160	167.0		7.0		163.6		3.6	
	180	186.7		6.7		183.7		3.7	
	200	206.2		6.2		203.7		3.7	

* DELTA T ON 18°F/DELTA T OFF 5°F

** DELTA T ON 9°F/Delta T OFF 4°F
Accuracy not specified by manufacturer

TABLE 18

CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF")
STORAGE -1.0°F/COLLECTOR +1.0°F

UNIT IIa

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IIa 18/5	60	77.9		17.9		67.9			7.9
	80	98.5		18.5		87.9			7.9
	100	118.8		18.8		107.8			7.8
	120	139.5		19.5		128.1			8.1
	140	160.1		20.1		148.4			8.4
	160	180.7			20.7	168.5			8.5
	180	200.8			20.8	188.9			8.9
	200	220.6			20.6	209.0			9.0

UNIT IIb

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	°F	<6.5°F	9°F ±2.5°F	>11.5°F	°F	<1.5°F	4°F ±2.5°F	>6.5°F
IIb 9/4	60	70.6		10.6		67.1			7.1
	80	90.5		10.5		87.0			7.0
	100	110.6		10.6		106.9			6.9
	120	130.8		10.8		127.0			7.0
	140	151.0		11.0		147.3			7.3
	160	170.7		10.7		167.3			7.3
	180	190.7		10.7		187.7			7.7
	200	210.0		10.0		207.8			7.8

* DELTA T ON 18°F/DELTA T OFF 5°F

** DELTA T ON 9°F/Delta T OFF 4°F
Accuracy not specified by manufacturer

temperature range, would turn off the solar unit too soon, negating the opportunity to add heat to storage.

The test results for TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF") for the single unit procured from a second manufacturer (IIa and IIb) and operating in the 18/5 and 9/4 modes are shown in tables 15 through 18. As noted, the baseline tests for this unit (Table 4 and 5), show that for each case the controller falls within the ±2.5°F controller tolerance assumed. This response is for both the delta T "ON" and the delta T "OFF" function using the nominal temperature/resistance tables. For the simulated storage sensor set at nominal +0.5°F and the collector resistance converted to delta T "ON" activation points at nominal -0.5°F (Table 15), Unit IIa is out-of-specification at low storage temperature settings. The delta T "OFF" function remains within specification. In simulating a reversal of the ±0.5°F tolerance sensors (Table 16), the delta T "OFF" for Unit IIa is outside-of-specification at high storage temperature settings while the other tests showed the controller to operate within specification. The results for the ±1.0°F tolerance sensors are shown in Tables 17 and 18.

Conclusions

As can be noted from the results, the controller's delta T "ON" and "OFF" response is a function of the sensor tolerance and that the tests described above accurately characterize this response. The effects of controller response using other sensors having different characteristics can also be determined using the test concept described above. However, no meaningful evaluation can be made unless the manufacturer provides the controller

delta T "ON" and "OFF" tolerance along with the tolerances which can be expected from the sensors to be used with that controller. Although beyond the scope of this report, an accurate measurement of sensor tolerances must be independently made if any confidence is to be given to the controller test results.

TEST 4 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (RECIRCULATING FREEZE PROTECTION)

Purpose

If provided as a controller feature or option, this test is intended to evaluate the controller's recirculating freeze protection response to the tolerance extremes that are characteristic of the sensor types specified for use with the controller.

Test Conditions

This test was conducted in a manner similar to the tests described under TEST 2 - RECIRCULATING FREEZE PROTECTION. For convenience, these tests may also be conducted in conjunction with TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF") or separately. Where TEST 2 - RECIRCULATING FREEZE PROTECTION uses the nominal temperature/resistance tables to simulate temperature inputs and to convert resistance readings to temperature activation responses, these tests use the modified nominal-plus-tolerance and nominal-minus-tolerance temperature/resistance tables developed for TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF").

The tests were conducted with fixed storage temperature increments of 20°F in the range between 60°F and 210°F corresponding to the points used for TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF"). The tests were first conducted with an assumed sensor tolerance of ±0.5°F, with a high reading sensor simulator (+0.5°F) providing the fixed storage temperature input and a simulated low reading collector sensor (-0.5°F) providing the activating element for the recirculating freeze protection option. Then the tests were conducted with the low reading sensor simulator (-0.5°F) providing the fixed storage temperature input and a simulated low reading collector sensor (+0.5°F) providing the activating element for the recirculating freeze protection option. The two tests were repeated using the appropriately modified ±1.0°F temperature/resistance tables.

The tests were conducted on each of the three identical controllers (IA, IB, and IC) and conducted separately for each delta T "ON" and "OFF" option (IIa and IIb) for the single controller procured from a second source. The tests were conducted at an ambient room temperature of approximately 70°F and at a nominal line voltage of 115 VAC at 60 Hertz.

Procedure

1. Use the modified nominal-plus-tolerance and the nominal-minus-tolerance temperature/resistance tables used for TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF").
2. Follow the procedure detailed for TEST 2 - RECIRCULATING FREEZE PROTECTION using the nominal-plus-tolerance for the storage input resistance and the nominal-minus-resistance tolerance to convert the

simulated collector resistance to pump activation/deactivation temperatures.

3. Repeat step 2 after increasing the simulated storage temperature by 20°F (by decreasing the resistance).

4. Repeat step 2 using the nominal-minus-tolerance for the storage input resistance and the nominal-plus-tolerance to convert the simulated collector resistance to pump activation/deactivation temperatures.

5. This test may be conducted in conjunction with TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA "ON" AND "OFF") by continuing to lower the simulated collector temperature (after the delta T "OFF" circuit deactivates the circulating pump) until the simulated temperature is reached where the circulating pump output is again activated by the recirculating freezer protection circuit. The simulated temperature is again raised (by decreasing the resistance) until the recirculating freezer protection is deactivated.

Results

The results of the controller response to the effects of sensor tolerance on the recirculating freeze protection function for three identical units procured from a single manufacturer (Units IA, IB, and IC) are shown in Tables 19 and 20 for the ±0.5°F tolerance sensors and Table 21 and 22 for the ±1.0°F tolerance sensors. The results of the same tests on a single unit procured from a second source, once in the 18/5 mode and a second time in the 9/4 mode (IIa and IIb), are shown in Tables 23 through 26.

For Units IA, IB, and IC, the controllers responded to the tolerance tests in almost the same manner as the tests using the nominal

Table 19

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE +0.5°F/COLLECTOR -0.5°F

UNITS IA, IB, IC

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IA 20/5	60		39.9				53.6
	80		39.9				52.9
	100		39.9				52.1
	120		39.8				51.2
	140		39.8				50.4
	160		39.8				49.6
	180		39.8				49.0
	200		39.8				48.6
IB 20/5	60		39.5				49.7
	80		39.4				48.3
	100		39.4				47.5
	120		39.4				47.0
	140		39.4				46.7
	160		39.4				46.5
	180		39.4				46.4
	200		39.4				46.3
IC 20/5	60		39.4				49.8
	80		39.4				48.4
	100		39.3				47.5
	120		39.3				47.0
	140		39.3				46.7
	160		39.3				46.5
	180		39.3				46.4
	200		39.3				46.3

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 20

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE -0.5°F/COLLECTOR +0.5°F

UNITS IA, IB, IC

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IA 20/5	60		40.9				54.6
	80		40.9				53.9
	100		40.9				53.1
	120		40.8				52.2
	140		40.8				51.3
	160		40.8				50.6
	180		40.8				50.0
	200		40.8				49.5
IB 20/5	60		40.5				50.7
	80		40.4				49.3
	100		40.4				48.5
	120		40.4				48.0
	140		40.4				47.7
	160		40.4				47.5
	180		40.4				47.4
	200		40.4				47.3
IC 20/5	60		40.4				50.8
	80		40.4				49.4
	100		40.3				48.5
	120		40.3				48.0
	140		40.3				47.7
	160		40.3				47.5
	180		40.3				47.4
	200		40.3				47.3

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 21

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE +1.0°F/COLLECTOR -1.0°F

UNITS IA, IB, IC

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IA 20/5	60		39.4				53.2
	80		39.4				52.5
	100		39.4				51.6
	120		39.3				50.7
	140		39.3				49.9
	160		39.3				49.2
	180		39.3				48.6
	200		39.3				48.0
IB 20/5	60		39.0				49.2
	80		38.9				47.8
	100		38.9				46.9
	120		38.9				46.5
	140		38.9				46.2
	160		38.9			46.0	
	180		38.9			45.9	
	200		38.9			45.8	
IC 20/5	60		38.9				49.3
	80		38.8				47.8
	100		38.8				47.0
	120		38.8				46.5
	140		38.8				46.2
	160		38.8			46.0	
	180		38.7			45.9	
	200		38.7			45.8	

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 22

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE -1.0°F/COLLECTOR +1.0°F

UNITS IA, IB, IC

Unit	Storage Temp Setting °F	Freeze Protection ON (Collector Temp) Outside Spec. (Low) <38°F	In Spec.** 40°±2°F	Outside Spec. (High) >42°F	Freeze Protection OFF (Collector Temp) Outside Spec. (Low) <42°F	In Spec.** 44°±2°F	Outside Spec. (High) >46°F
IA 20/5	60		41.4				55.1
	80		41.4				54.4
	100		41.4				53.5
	120		41.3				52.7
	140		41.3				51.8
	160		41.3				51.1
	180		41.3				50.5
	200		41.3				50.1
IB 20/5	60		41.0				51.2
	80		40.9				49.8
	100		40.9				49.0
	120		40.9				48.5
	140		40.9				48.2
	160		40.9				48.0
	180		40.9				47.9
	200		40.9				47.8
IC 20/5	60		40.9				51.3
	80		40.9				49.9
	100		40.8				49.0
	120		40.8				48.5
	140		40.8				48.2
	160		40.8				48.0
	180		40.8				47.9
	200		40.8				47.1

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 23

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE +0.5°F/COLLECTOR -0.5°F

UNITS IIa, IIb

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IIa 18/5	60		41.3			45.3	
	80		41.4			44.9	
	100		41.5			44.7	
	120		41.6			44.6	
	140		41.6			44.5	
	160		41.6			44.5	
	180		41.6			44.4	
	200		41.6			44.4	
IIb 9/4	60		41.2			45.3	
	80		41.4			45.0	
	100		41.5			44.7	
	120		41.6			44.6	
	140		41.6			44.5	
	160		41.6			44.5	
	180		41.6			44.4	
	200		41.6			44.4	

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

Table 24

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE -0.5°F/COLLECTOR +0.5°F

UNITS IIa, IIb

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IIa 18/5	60			42.3			46.3
	80			42.4		45.9	
	100			42.5		45.7	
	120			42.6		45.6	
	140			42.6		45.5	
	160			42.6		45.5	
	180			42.6		45.4	
	200			42.6		45.4	
IIb 9/4	60			42.3			46.3
	80			42.4		45.9	
	100			42.5		45.7	
	120			42.6		45.6	
	140			42.6		45.5	
	160			42.6		45.5	
	180			42.6		45.4	
	200			42.6		45.4	

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

Table 25

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE +1.0°F/COLLECTOR -1.0°F

UNITS IIa, IIb

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IIa 18/5	60		40.8			44.8	
	80		40.9			44.5	
	100		41.0			44.2	
	120		41.1			44.1	
	140		41.1			44.0	
	160		41.1			44.0	
	180		41.1			43.9	
	200		41.1			43.9	
IIb 9/4	60		40.8			44.8	
	80		40.9			44.5	
	100		41.0			44.2	
	120		41.1			44.1	
	140		41.1			44.0	
	160		41.1			44.0	
	180		41.1			43.9	
	200		41.1			43.9	

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

Table 26

CONTROLLER RESPONSE TO SENSOR TOLERANCE* (RECIRCULATING FREEZE PROTECTION)
STORAGE -1.0°F/COLLECTOR +1.0°F

UNITS IIa, IIb

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IIa 18/5	60			42.8			46.8
	80			42.9			46.4
	100			43.0			46.2
	120			43.1			46.1
	140			43,1			46.1
	160			43.1		46.0	
	180			43.1		45.9	
	200			43.1		45.9	
IIb 9/4	60			42.7			46.8
	80			42.9			46.4
	100			43.0			46.2
	120			43.1			46.1
	140			43.1		46.0	
	160			43.1		46.0	
	180			43.1		45.9	
	200			43.1		45.9	

* Test run concurrently with CONTROLLER RESPONSE TO SENSOR SENSITIVITY (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

TABLE 27

CONTROLLER RESPONSE TO SENSOR TOLERANCE
(RECIRCULATING FREEZE PROTECTION)
CHANGES IN VALUE FROM BASELINE

UNIT IA

RECIRCULATING FREEZE PROTECTION "ON"

Storage Temp. Setting	Collector Tolerance								
	Nominal	Nominal Minus 0.5°F	Nominal Plus 0.5°F	Change (3)-(2)	Change (4)-(2)	Nominal Minus 1.0°F	Nominal Plus 1.0°F	Change (7)-(2)	Change (8)-(2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
60	40.5	39.9	40.9	-0.6	0.4	39.4	41.4	-1.1	0.9
80	40.3	39.9	40.9	-0.4	0.6	39.4	41.4	-0.9	1.1
100	40.3	39.9	40.9	-0.4	0.6	39.4	41.4	-0.9	1.1
120	40.2	39.8	40.8	-0.4	0.6	39.3	41.3	-0.9	1.1
140	40.2	39.8	40.8	-0.4	0.6	39.3	41.3	-0.9	1.1
160	40.2	39.8	40.8	-0.4	0.6	39.3	41.3	-0.9	1.1
180	40.2	39.8	40.8	-0.4	0.6	39.3	41.3	-0.9	1.1
200	40.2	39.8	40.8	-0.4	0.6	39.3	41.3	-0.9	1.1

RECIRCULATING FREEZE PROTECTION "OFF"

60	54.1	53.6	54.6	-0.5	0.5	53.2	55.1	-0.9	1.0
80	53.3	52.9	53.9	-0.4	0.6	52.5	54.4	-0.8	1.1
100	52.5	52.1	53.1	-0.4	0.6	51.6	53.5	-0.9	1.0
120	51.6	51.2	52.2	-0.4	0.6	50.7	52.7	-0.9	1.1
140	50.8	50.4	51.3	-0.4	0.5	49.9	51.8	-0.9	1.0
160	50.1	49.6	50.6	-0.5	0.5	49.2	51.1	-0.9	1.0
180	49.5	49.0	50.0	-0.5	0.5	48.6	50.5	-0.9	1.0
200	49.0	48.6	49.5	-0.4	0.5	48.0	50.1	-1.0	1.1

(1) Storage temperature resistance determined from appropriately modified tolerance table i.e. simulated storage temperature set at nominal-plus 0.5°F for nominal-minus 0.5°F controller readings.
(2) Data from Table 6
(3) Data from Table 19
(4) Data from Table 20
(7) Data from Table 21
(8) Data from Table 22

TABLE 28

CONTROLLER RESPONSE TO SENSOR TOLERANCE
(RECIRCULATING FREEZE PROTECTION)
CHANGES IN VALUE FROM BASELINE

UNIT IIa

RECIRCULATING FREEZE PROTECTION "ON"

Storage Temp. Setting	Collector Tolerance								
	Nominal	Nominal Minus 0.5°F	Nominal Plus 0.5°F	Change (3)-(2)	Change (4)-(2)	Nominal Minus 1.0°F	Nominal Plus 1.0°F	Change (7)-(2)	Change (8)-(2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
60	41.7	41.3	42.3	-0.4	0.6	40.8	42.8	-0.9	1.1
80	41.8	41.4	42.4	-0.4	0.6	40.9	42.9	-0.9	1.1
100	41.9	41.5	42.5	-0.4	0.6	41.0	43.0	-0.9	1.1
120	42.0	41.6	42.6	-0.4	0.6	41.1	43.1	-0.9	1.1
140	42.0	41.6	42.6	-0.4	0.6	41.1	43.1	-0.9	1.1
160	42.0	41.6	42.6	-0.4	0.6	41.1	43.1	-0.9	1.1
180	42.0	41.6	42.6	-0.4	0.6	41.1	43.1	-0.9	1.1
200	42.0	41.6	42.6	-0.4	0.6	41.1	43.1	-0.9	1.1

RECIRCULATING FREEZE PROTECTION "OFF"

60	45.8	45.3	46.3	-0.5	0.5	44.8	46.8	-1.0	1.0
80	45.4	44.9	45.9	-0.5	0.4	44.5	46.4	-0.9	1.0
100	45.2	44.7	45.7	-0.5	0.5	44.2	46.2	-1.0	1.0
120	45.0	44.6	45.6	-0.4	0.6	44.1	46.1	-0.9	1.1
140	44.9	44.5	45.5	-0.4	0.6	44.0	46.1	-0.9	1.2
160	44.9	44.5	45.5	-0.4	0.6	44.0	46.0	-0.9	1.1
180	44.9	44.4	45.4	-0.5	0.6	43.9	45.9	-1.0	1.0
200	44.8	44.4	45.4	-0.4	0.6	43.9	45.9	-0.9	1.1

(1) Storage temperature resistance determined from appropriately modified tolerance table i.e. simulated storage temperature set at nominal-plus 0.5°F for nominal-minus 0.5°F controller readings.
(2) Data from Table 9
(3) Data from Table 23
(4) Data from Table 24
(7) Data from Table 25
(8) Data from Table 26

temperature/resistance tables. All units in each recirculating freeze protection "ON" test were within the accuracy specified by the manufacturer. They also were all out-of-specification for the recirculating freeze protection "OFF" tests except for units IB and IC which shifted to in-specification values at 160, 180, and 200 °F when the simulated storage temperature was at nominal-plus 1.0°F and the simulated collector temperature at nominal-minus 1.0°F. The tolerance test results on units IIa and IIb, however, varied to a greater degree from the nominal temperature/resistance tests.

When the test results for the tolerance tests are compared to the nominal tests and the changes noted, a consistent pattern evolves. Only two sets of results are shown (Table 27 for unit IA and Table 28 for unit IIa) as the results for the other units would display similar patterns. As can be noted from Tables 27 and 28, the changes from nominal approximately correspond to the tolerance of the collector sensor. This is not surprising since the collector sensor is the controlling element which determines the activation and deactivation of the circulating pump.

Conclusions

Because the collector sensor controls the activation and deactivation of the recirculating freeze protection function, it seems that the behavior of the controller in this mode can be predicted by adding the collector tolerance to the results of the tests that use the nominal temperature/resistance tables. If the nominal tests show that the controller is activated or deactivated near the center of the tolerance range and the sensor tolerance limits are narrow, the resulting responses

for both high and low tolerance sensors will probably be within specification. If the nominal tests show that the controller response to recirculating freeze protection is at the borderline of the specified controller tolerance, the collector sensor tolerances should drive the controller out of tolerance for either the high or low tolerance collector sensor test and closer to the nominal results with the complimentary tolerance test. If there is any doubt about the controller response predictability of the analytical method, a single test may be conducted on the first unit tested and the analytical method used for all subsequent units of the same type collector. Since the tests are not difficult to run, especially if conducted in conjunction with TEST 3 - CONTROLLER RESPONSE TO SENSOR TOLERANCE (DELTA T "ON" AND "OFF"), the evaluation approach that requires the testing of each unit is a reasonable alternative.

TEST 5 - STORAGE HIGH TEMPERATURE LIMIT

Purpose

This test is intended to evaluate the controller's storage high temperature limit response, if provided as a controller feature or option.

Test Conditions

The storage high limit temperature limit function is intended to protect the storage tank liquid from reaching high temperatures by cutting-off the circulating pump when the liquid in the tank reaches a predetermined temperature. This temperature is set on the three units procured from a single manufacturer (units IA, IB, and IC) by rotating a trimpot knob on the circuit board until a molded-in arrow on the knob points to the desired temperature. Temperatures specifically indicated are 105, 120, 140, 180,

and 212°F (High Limit Out). Temperature settings between these markings are made by positioning the arrow on the knob to the approximate setting. Tests were only conducted with the arrow pointing to one of the discretely marked setting noted above. The unit procured from a second manufacturer is adjusted by a series of rocker switches mounted on the controller's circuit board with setting options of 160°F, 180°F, or "OFF". Tests were conducted at the two storage high temperature limit settings in both the 18/5 mode and in the 9/4 mode (IIa and IIb). It should be noted that for all tests (except this STORAGE HIGH TEMPERATURE LIMIT test) the high limit option is set to the "OFF" position.

Since this function deactivates the circulating pump, the controller's simulated operation at the start of this test must be such that the pump is in the activated mode in order to observe the change. Also, the tests must be conducted so that the simulated temperatures chosen are not in the range whereby the pump output is deactivated by a different controller function such as DELTA T "OFF". The tests are conducted by setting the simulated storage temperature below the storage high limit test temperature setting and the simulated collector temperature at the storage high limit test temperature plus 1.5 times the DELTA T "ON" specified for the controller. For example, if the storage high limit to be tested is 160°F and the controller delta T "ON" is 20°F, the simulated storage sensor is set below 160°F and the simulated collector temperature at 190°F (storage high limit test temperature [160°F] plus delta T "ON" for the controller [20°F] times 1.5 [30°F]). This large delta T will cause the pump output to be activated. The simulated storage temperature is then raised until the pump output is deactivated then lowered until the pump output is reactivated.

It should be noted that if the simulated collector temperature were set too low, say 165°F, and the delta T "OFF" for the controller is 5°F, any delta T "OFF" function deactivating the pump output might be mistaken for the storage high temperature limit output.

Tests on all units were conducted at an ambient room temperature of approximately 70°F and at a nominal line voltage of 115 VAC at 60 Hertz.

Procedure

1. All tests are conducted using the nominal temperature/resistance tables provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Set the storage sensor simulated temperature at approximately 10°F lower than the storage high temperature limit to be tested.
3. Set the collector sensor at a simulated storage temperature calculated by adding the storage high temperature limit to be tested to 1.5 times the delta T for the collector.
4. Increase the storage simulated temperature (by decreasing the resistance) until the pump output is deactivated and record the resistance corresponding to the storage high temperature limit deactivation temperature.
5. Decrease the storage simulated temperature (by increasing the resistance) until the pump output is again activated and record the resistance corresponding to the storage high temperature limit reactivation temperature.
6. For units with infinitely adjustable storage high limit temperature controls, conduct the initial test at the lowest storage high

temperature limit setting as described in steps 2, 3, and 4 above and each subsequent test at the next higher discrete temperature marking but not less than every 10°F. Continue testing until a representative number of tests are performed over the entire range of storage high temperature limits.

7. For units with discretely settable storage high temperature limits, test each unit as described in steps 2, 3, and 4 above for each discrete setting.

8. Convert the recorded resistances to operating temperatures using the nominal temperature/resistance tables appropriate for the simulated sensor.

Results

The controllers' response to TEST 5 - STORAGE HIGH TEMPERATURE LIMIT is shown in Table 29. The specifications for units IA, IB, and IC call for a ±2°F tolerance for this function. The literature for the unit procured from a second source (IIa, IIb) provide no tolerance limits and, for purposes of this report, a tolerance of ±2°F for this unit was assumed. As can be observed from Table 29, the three identical units procured from a single manufacturer were generally outside-of-specification for the storage high temperature limit function (except for the storage high temperature "OFF" for some of the lower temperature settings for units IA and IC). The unit procured from a second source was also outside-of-specification for storage high temperature (PUMP "OFF") but within the assumed specification for storage high temperature (PUMP "ON") in both the 18/5 and 9/4 mode (IIa and IIb).

Table 29

CONTROLLER RESPONSE TO STORAGE HIGH TEMPERATURE LIMIT

UNITS IA, IB, IC; IIa, IIb

Unit	Storage High Temp Limit Setting	Storage High Temperature (Pump OFF)			Storage High Temperature (Pump ON)		
		Outside Spec. (Low) Setting <-2°F	In Spec.* Setting ±2°F	Outside Spec. (High) Setting >+2°F	Outside Spec. (Low) Setting <-2°F	In Spec.* Setting ±2°F	Outside Spec. (High) Setting >+2°F
IA 20/5	105		103.9		101.7		
	120		119.1		115.7		
	140	135.8			132.2		
	180	171.7			163.0		
IB 20/5	105	101.0			98.8		
	120	113.3			111.1		
	140	130.3			127.9		
	180	167.9			165.3		
IC 20/5	105		103.9		101.7		
	120	116.8			114.6		
	140	135.8			133.9		
	180	166.2			163.9		
IIa 18/5	160			163.8		160.9	
	180			184.4		181.5	
IIb 9/4	160			163.8		160.8	
	180			184.4		181.7	

* Accuracy specified by manufacturer for units IA, IB, and IC is ±2°F. Accuracy not specified for unit IIa, IIb - Assumed to be the same as units IA, IB, and IC.

Conclusions

The tests conducted seem to characterize the CONTROLLER RESPONSE TO STORAGE HIGH TEMPERATURE LIMIT in a reasonable manner. It should be noted that had the tolerance limits been specified for a wider range (say ±5°F) the units would have been said to respond better. Since the accuracy of this function on overall controller operation is not as critical as other functions (such as delta T "ON" and "OFF"), a controller specification with different tolerances for each function may be more appropriate instead of a single controller tolerance for all functions.

TEST 6 - RECIRCULATING FREEZE PROTECTION USING AUXILIARY SENSOR

Purpose

If provided as a special control feature or option, this test is to evaluate the controller's recirculating freeze protection response using an auxiliary sensor to control this function. As a by-product of this test the effect of the auxiliary sensor on the controller's delta T "ON" and "OFF" response is also evaluated.

Test Conditions

The three identical units procured from a single manufacturer (units IA, IB, and IC) were provided with the option for using an auxiliary sensor to activate the recirculating freeze protection feature by moving a jumper connector on the input to the controller. This feature was not provided on the controller procured from a second source (unit IIa, IIb); therefore, this test does not apply to this controller. Tests for units which use the collector sensor to activate the controllers recirculating freeze protection function are described under TEST 2 - RECIRCULATING FREEZE PROTECTION.

This test simulates a solar system containing a controller and three sensors. One sensor determines the storage tank temperature; another the collector temperature; and the third, the auxiliary sensor, measures the outdoor ambient conditions. As such, three simulated inputs (decade resistance boxes) are used. The tests are started by setting each simulated temperature at a storage test temperature. The simulated collector temperature is then elevated until the delta T "ON" function is activated, and then lowered until the delta T "OFF" signal deactivates the pump output. The delta T "ON" and "OFF" points are recorded to assess the effects of the auxiliary recirculating freeze protection sensor circuit, if any, on the operation of the controller.

The simulated collector temperature is then lowered to the nominal recirculating freeze protection activation temperature and fixed at this point to approximate the operating temperature of the collector at recirculating freeze protection activation by the auxiliary sensor. The simulated temperature of the auxiliary recirculating freeze protection sensor is then lowered until the sensor activates the pump output and the operating point recorded. The simulated temperature is then increased until the pump output is deactivated and the simulated deactivation temperature recorded.

The tests are conducted using the nominal temperature/resistance table and repeated at storage settings of 20°F intervals. Tolerance tests are generally not warranted since the controller's response to a variety of

changing conditions have been conducted earlier and the controller's characteristics are generally known by the time this test is performed. TEST 6 - RECIRCULATING FREEZE PROTECTION USING AUXILIARY SENSOR was conducted at an ambient temperature of approximately 70°F with power supplied at 115 VAC at 60 Hertz.

Procedure

1. All tests are conducted using the nominal temperature/resistance table provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Set all the simulated temperatures (resistance) for the storage, collector, and auxiliary inputs to correspond to the lowest storage temperature used in conducting the BASELINE FUNCTIONAL TESTS (DELTA T "ON" AND "OFF").
3. Increase the collector sensor simulated temperature (by decreasing the resistance) until the pump output is activated and record the resistance corresponding to the delta T "ON" temperature.
4. Decrease the collector sensor simulated temperature (by increasing the resistance) until thr pump output is deactivated and record the resistance corresponding to the delta T "OFF" temperature.
5. Decrease the simulated collector sensor temperature (by increasing the resistance) to a setting corresponding to the nominal recirculating freeze protection temperature.
6. Decrease the simulated auxiliary recirculating freeze protection sensor (by increasing the resistance) until the pump output is activated and record the resistance corresponding to the recirculating freeze protection "ON" temperature.

7. Increase the simulated auxiliary recirculating freeze protection sensor (by decreasing the resistance) until the pump output is deactivated and record the resistance corresponding to the recirculating freeze protection "OFF" temperature.
8. Repeat step 2 after increasing the simulated storage, collector, and auxiliary temperatures by 20°F (by decreasing the resistance).
9. Repeat steps 3 through 7.
10. Continue this procedure over the storage temperature range used in conducting TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF").
11. Convert the recorded resistances to operating temperatures using the nominal temperature/resistance table appropriate for the simulated sensor.

<u>Results</u>

The results of tests for units IA, IB, and IC characterizing the CONTROLLER RESPONSE USING AUXILIARY SENSOR INPUT (DELTA T "ON" AND "OFF") are shown in Table 30. If these test results are compared to the results obtained for TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF"), it will be noted that the controller's response in both tests are almost identical (see Table 1). In fact, they do not vary at all for the delta T "ON" tests and vary only slightly (a few tenths of a °F, at most), at the higher storage temperature settings. Effectively, this means that for these controllers, the delta T "ON" and "OFF" function is virtually unchanged over the controller's overall operating range by the presence of the auxiliary recirculating freeze protection sensor in the circuit.

The controller's response to recirculating freeze protection using the

TABLE 30

CONTROLLER RESPONSE USING AUXILIARY SENSOR INPUT (DELTA T "ON" AND "OFF")

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IA 20/5	60	77.8		17.8		65.8		5.8	
	80	98.8		18.8		85.9		5.9	
	100	119.8		19.8		106.0		6.0	
	120	140.7		20.7		126.0		6.0	
	140	161.2		21.2		145.7		5.7	
	160	181.6		21.6		165.0		5.0	
	180	201.5		21.5		183.9		3.9	
	200	221.2		21.2		202.3	2.3		
IB 20/5	60	77.2	17.2			65.4		5.4	
	80	98.2		18.2		85.4		5.4	
	100	119.1		19.1		105.6		5.6	
	120	140.0		20.0		125.5		5.5	
	140	160.5		20.5		145.2		5.2	
	160	180.9		20.9		164.5		4.5	
	180	200.7		20.7		183.3		3.3	
	200	220.4		20.4		201.7	1.7		
IC 20/5	60	77.8		17.8		65.9		5.9	
	80	98.9		18.9		86.0		6.0	
	100	119.8		19.8		106.1		6.1	
	120	140.8		20.8		126.1		6.1	
	140	161.3		21.3		145.9		5.9	
	160	181.7		21.7		165.1		5.1	
	180	201.7		21.7		184.0		4.0	
	200	221.4		21.4		202.4	2.4		

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

Table 31

CONTROLLER RESPONSE USING AUXILIARY SENSOR INPUT* (RECIRCULATING FREEZE PROTECTION)

UNITS IA, IB, IC

Unit	Storage Temp Setting	Freeze Protection ON (Auxiliary Sensor Temp)			Freeze Protection OFF (Auxiliary Sensor Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IA 20/5	60		38.6				46.3
	80		39.4			46.0	
	100		39.9			45.8	
	120		40.2			45.7	
	140		40.4			45.7	
	160		40.5			45.6	
	180		40.6			45.6	
	200		40.6			45.6	
IB 20/5	60		38.5			45.8	
	80		39.3			45.6	
	100		39.7			45.4	
	120		40.0			45.3	
	140		40.2			45.3	
	160		40.3			45.3	
	180		40.4			45.2	
	200		40.4			45.2	
IC 20/5	60		38.5				46.1
	80		39.3			45.7	
	100		39.8			45.6	
	120		40.0			45.5	
	140		40.2			45.4	
	160		40.3			45.4	
	180		40.4			45.4	
	200		40.4			45.4	

* Test run concurrently with CONTROLLER RESPONSE USING AUXILIARY SENSOR INPUT (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

auxiliary sensor for the input is shown in Table 31. Each tested unit operated within the specified tolerance except units IA and IC which was out-of-specification for the 60°F storage setting. This is contrasted to the results obtained for units IA, IB and IC when the collector sensor was used for TEST 2 - RECIRCULATING FREEZE PROTECTION (Tables 6, 7, and 8). These tables indicate that the Freeze Protection "OFF" function was greatly out-of-specification for all units. The test results show that for these specific units, the controller operation using the auxiliary sensor for recirculating freeze protection is a more desirable mode than using the collector sensor for this function.

Conclusions

This test appears to adequately indicate the response of the controller to recirculating freeze protection when using an auxiliary sensor to activate this function. It also provides the data to assess the effects, if any, of the presence of the auxiliary sensor on the delta T "ON" and "OFF" function.

TEST 7 - PUMP "OFF" BELOW 80°F

Purpose

If provided as a special control feature or option, this test is intended to evaluate the controller's PUMP "OFF" BELOW 80°F function.

Test Conditions

The single controller tested (Unit IIa, IIb) was equipped with a PUMP "OFF" BELOW 80°F option that is set by a rocker switch on the printed circuit board. Setting this switch prevents the pump from being activated when the

collector is below 80°F. This feature prevents water circulation at night after a large amount of water has been consumed or when a reverse thermosyphon effect would normally cause the pump to turn on. Setting the recirculating freeze protection switch, however, overrides this option. The test was performed twice; once with the controller in the 18/5 mode (IIa) and the second time with the controller in the 9/4 mode (IIb). Units IA, IB, and IC did not have the PUMP "OFF" BELOW 80°F feature.

The test must be conducted with the pump output activated and care must be taken to assure that the PUMP "OFF" BELOW 80°F function is the pump deactivation stimulus rather than some other functional input such as DELTA T "OFF". In this regard, the test is conducted with the simulated storage and collector temperature at 60°F and the simulated collector temperature raised to approximately 90°F. Since the delta T "ON" in the 18/5 mode (IIa) and in 9/4 mode (IIb) is well exceeded with the simuulated collector temperature at 90°F and the simulated storage temperature at 60°F, the pump output is in an activated state. The simulated collector temperature is then lowered until the PUMP "OFF" BELOW 80°F function deactivates the pump output and the deactivation point recorded. The simulated temperature is then raised until the pump is again activated and that operating point also recorded. Since the pump deactivated near 80°F, it can be assumed that the PUMP "OFF" BELOW 80°F function deactivated the pump output and not the controller's delta T "OFF" circuit. This is because with the simulated storage temperature set at 60°F, the delta T "OFF" for the controller in the 18/5 mode (IIa) would be near 65°F and in the 9/4 mode (IIb) near 64°F and not in the 80°F range.

The PUMP "OFF" BELOW 80°F tests were conducted at an ambient temperature of approximately 70°F with power supplied at 115 VAC at 60 Hertz.

Procedure

1. All tests are conducted using the nominal temperature/resistance table provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Set the simulated temperature (resistance) for the storage and collector inputs to 60°F.
3. Increase the collector simulated temperature (by decreasing the resistance) to a value corresponding to 90°F, activating the pump output.
4. Decrease the collector simulated temperature (by increasing the resistance) until the pump output is deactivated and record the resistance corresponding to the PUMP "OFF" BELOW 80°F temperature.
5. Increase the collector simulated temperature (by increasing the resistance) until the pump output is activated and record the resistance.
6. Convert the recorded resistance to operating temperatures using the nominal temperature/resistance table appropriate for the simulated sensor.

Results

The PUMP "OFF" BELOW 80°F test results are shown in Table 32. Since no tolerance limits were provided for this function, a controller tolerance of ±2°F were assumed for purposes of this report. The unit was within this specification in both the 18/5 mode (IIa) and the 9/4 mode (IIb). Since this function is not critical to the basic operation of the controller,

TABLE 32

PUMP "OFF" BELOW 80°F

UNIT IIa, IIb

Unit	Pump Output "OFF"			Pump Output "ON"		
	Outside Spec (Low) <78°F	In Spec 80°±2°F	Outside Spec (High) >82°F	Outside Spec (Low) <78°F	In Spec 80°±2°F	Outside Spec (High) >82°F
IIa 18/5		78.9			81.5	
IIb 9/4		78.9			81.5	

(such as the delta T "ON" and "OFF" function), perhaps an assignment by the manufacturer of a tolerance of ±5°F may be appropriate.

Conclusions

This test appears to adequately indicate the response of the controller to the optional PUMP "OFF" BELOW 80°F function.

SENSITIVITY TO LINE VOLTAGE FLUCTUATION - (AMBIENT)

THE FOLLOWING TESTS WERE CONDUCTED TO EVALUATE THE CONTROLLER'S SENSITIVITY TO LINE VOLTAGE FLUCTUATION. WITH THE COMPLETION OF THE CONTROLLER'S FUNCTIONAL TESTS DESCRIBED EARLIER, THE CONTROLLER'S RESPONSE UNDER A VARIETY OF INPUTS ARE CHARACTERIZED. AS SUCH, IT IS LIKELY THAT ONLY THE TWO TESTS DESCRIBED BELOW ARE NEEDED TO EVALUATE THE CONTROLLER'S RESPONSE TO VARIABLE LINE VOLTAGES. THE TESTS WERE CONDUCTED AT AMBIENT CONDITIONS OF APPROXIMATELY 70°F.

TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND OFF)

Purpose

This test is intended to characterize the controller's delta T "ON" and "OFF" response to line voltage fluctuation.

Test Conditions

Where TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") was run with the input voltage at a nominal 115 VAC at 60 Hertz, these tests are conducted with the electrical input to the controller at both the low and high voltage limits specified by the manufacturer. To accomplish this, the power input to the controller was supplied through a variac and the

indicated voltage on the variac confirmed by a separate voltmeter (see Fig. 1). Because the specification for voltage input limits were inconsistent in the manufacturer's literature, for purposes of this report the tests were conducted at 90 VAC and later repeated at 130 VAC.

This test is identical to TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") except that data are collected at sensor storage increments of 20°F instead of 5°F. This increment is sufficient to compare the controller's line voltage characteristics when used in conjunction with the more detailed baseline test. Tests were conducted on the three identical controllers procured from a single manufacturer (units IA, IB, and IC). Tests were also conducted on the single unit procured from a second source; once in the 18/5 mode (IIa) and once in the 9/4 mode (IIb).

All tests were conducted at an ambient room temperature of approximately 70°F.

<u>Procedure</u>

1. All tests are conducted using the nominal temperature/resistance table provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Using a variac, or other adjustable voltage device, provide input power to the controller at the specified low voltage tolerance and maintain this voltage throughout the test.
3. Set the storage and collector sensor simulated temperatures (resistance) to correspond to the lowest storage temperature used in conducting TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF").

4. Conduct TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF") by following the procedure detailed for TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") except the storage temperature increments are increased by 20°F instead of 5°F.
5. Repeat steps 2 through 4 after resetting the variac or other adjustable voltage device to the manufacturer's high voltage tolerance specification.

Results

The results for TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF") are shown in Tables 33 through 36. Table 33 and 34 indicate the test results for units IA, IB, and IC at 90 VAC and 130 VAC respectively. Tables 35 and 36 indicate the tests result for the single unit procured from a second source and tested in the 18/5 mode (IIa) and the 9/4 mode (IIb) at 90 VAC and 130 VAC.

The data for TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF") for the three identical units tested (IA, IB, and IC) at both 90 VAC and 130 VAC (Tables 33 and 34) were compared to the data collected for these units under TEST 1 - BASELINE FUNCTIONAL TEST (DELTA T "ON" AND "OFF") at a nominal operating voltage of 115 VAC (Tables 1, 2, and 3). The response of all the controllers were generally identical for all voltages over the entire range of tested storage temperature settings with a few delta T readings not corresponding by a few tenths of a degree. Where the units were out-of-specification in the baseline tests, they were also out-of-specification in the line voltage fluctuation tests and it can be reasonably assessed that these units are not voltage sensitive over the

voltage range tested at room ambient conditions of approximately 70°F.

A similar comparison made for unit IIa and IIb indicate different results. In comparing the data for TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF") at 90 VAC and 130 VAC (Tables 35 and 36) with baseline data conducted at 115 VAC (Tables 4 and 5), it can be noted that the controller response in the delta T "ON" mode is rather consistent at all voltages. However, the controller's response in the delta T "OFF" mode shows a significant difference at the higher storage temperature tests at 90 VAC. For illustration and ease of analysis, these data are plotted in Figure 5 for the unit operating in the 18/5 mode (IIa). For a controller operating tolerance of ±2.5°F, it can be seen that the nominal controller operation is within the ±2.5°F tolerance for the delta T "ON" function over the entire operating range for all voltages between 90 VAC and 130 VAC with little variation for the different voltages. For the delta T "OFF" function, the controller goes out-of-specification at a storage setting of approximately 165°F when operated at 130 VAC. Although not plotted, an inspection of the data reveals that the controller exhibits similar delta T "ON" and "OFF" characteristics when operated in the 9/4 mode (IIb).

The above discussion brings to light that no measure of acceptable performance due strictly to voltage variation is indicated. In effect, if the controller responds exactly the same when operated at the test voltage, we can say that the controller is not sensitive to line voltage fluctuation. If there are different responses to the test voltages, however, the means of expressing and quantifying these differences is not

TABLE 33

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")

90 VAC

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IA 20/5	60	77.8		17.8		65.8		5.8	
	80	98.8		18.8		85.9		5.9	
	100	119.8		19.8		106.0		6.0	
	120	140.7		20.7		126.0		6.0	
	140	161.2		21.2		145.6		5.6	
	160	181.6		21.6		164.8		4.8	
	180	201.6		21.6		183.6		3.9	
	200	221.2		21.2		201.9	1.9		
IB 20/5	60	77.2	17.2			65.4		5.4	
	80	98.2		18.2		85.4		5.4	
	100	119.1		19.1		105.6		5.6	
	120	140.1		20.1		125.5		5.5	
	140	160.5		20.5		145.2		5.2	
	160	180.9		20.9		164.4		4.4	
	180	200.7		20.7		183.3		3.1	
	200	220.4		20.4		201.4	1.4		
IC 20/5	60	77.8		17.8		65.8		5.8	
	80	98.9		18.9		85.9		5.9	
	100	119.8		19.8		106.1		6.1	
	120	140.8		20.8		126.0		6.0	
	140	161.3		21.3		145.7		5.7	
	160	181.7		21.7		164.9		4.9	
	180	201.7		21.7		183.7		3.7	
	200	221.4		21.4		202.0	2.0		

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 34

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")

130 VAC

UNIT IA, IB, IC

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<17.5°F	20°F ±2.5°F	>22.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
	60	77.8		17.8		65.8		5.8	
	80	98.8		18.8		85.9		5.9	
	100	119.8		19.8		106.0		6.0	
IA	120	140.7		20.7		126.0		6.0	
20/5	140	161.3		21.3		145.7		5.7	
	160	181.6		21.6		164.9		4.9	
	180	201.6		21.6		183.7		3.7	
	200	221.2		21.2		202.0	2.0		
	60	77.2	17.2			65.4		5.4	
	80	98.2		18.2		85.4		5.4	
	100	119.1		19.1		105.5		5.5	
IB	120	140.0		20.0		125.5		5.5	
20/5	140	160.5		20.5		145.2		5.2	
	160	180.9		20.9		164.4		4.4	
	180	200.7		20.7		183.1		3.1	
	200	220.3		20.3		201.4	1.4		
	60	77.8		17.8		65.9		5.9	
	80	98.9		18.9		86.0		6.0	
	100	119.8		19.8		106.1		6.1	
IC	120	140.8		20.8		126.1		6.1	
20/5	140	161.3		21.3		145.8		5.8	
	160	181.7		21.7		165.0		5.0	
	180	201.7		21.7		183.8		3.8	
	200	221.4		21.4		202.2	2.2		

* Accuracy specified by manufacturer - Delta T ON 20°F ± 2.5°F
Delta T OFF 5°F ± 2.5°F

TABLE 35

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")
90 VAC

UNIT IIa

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IIa 18/5	60	75.7		15.7		66.1		6.1	
	80	96.4		16.4		86.1		6.1	
	100	116.7		16.7		106.2		6.2	
	120	137.4		17.4		126.5		6.5	
	140	158.1		18.1		147.0		7.0	
	160	178.5		18.5		167.2		7.2	
	180	198.8		18.8		187.9			7.9
	200	218.9		18.9		208.7			8.7

UNIT IIb

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	°F	<6.5°F	9°F ±2.5°F	>11.5°F	°F	<1.5°F	4°F ±2.5°F	>6.5°F
IIb 9/4	60	68.4		8.4		65.3		5.3	
	80	88.5		8.5		85.3		5.3	
	100	108.5		8.5		105.3		5.3	
	120	128.7		8.7		125.5		5.5	
	140	148.9		8.9		146.0		6.0	
	160	168.8		8.8		166.3		6.3	
	180	188.6		8.6		186.9			6.9
	200	208.2		8.2		207.6			7.6

* DELTA T ON 18°F/DELTA T OFF 5°F

** DELTA T ON 9°F/Delta T OFF 4°F
Accuracy not specified by manufacturer

TABLE 36

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")
130 VAC

UNIT IIa

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.*	Outside Spec. (High)
	°F	°F	<15.5°F	18°F ±2.5°F	>20.5°F	°F	<2.5°F	5°F ±2.5°F	>7.5°F
IIa 18/5	60	75.7		15.7		65.8		5.8	
	80	96.4		16.4		85.8		5.8	
	100	116.7		16.7		105.8		5.8	
	120	137.4		17.4		125.9		5.9	
	140	158.0		18.0		146.2		6.2	
	160	178.5		18.5		166.3		6.3	
	180	198.8		18.8		186.5		6.5	
	200	219.0		19.0		206.6		6.6	

UNIT IIb

Unit	Storage Temp Setting	Delta T ON				Delta T OFF			
		Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Collector Temp.	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	°F	<6.5°F	9°F ±2.5°F	>11.5°F	°F	<1.5°F	4°F ±2.5°F	>6.5°F
IIb 9/4	60	68.4		8.4		65.0		5.0	
	80	88.5		8.5		84.9		4.9	
	100	108.5		8.5		104.8		4.8	
	120	128.7		8.7		124.9		4.9	
	140	148.9		8.9		145.2		5.2	
	160	168.8		8.8		165.2		5.2	
	180	188.6		8.6		185.2		5.2	
	200	208.2		8.2		205.3		5.3	

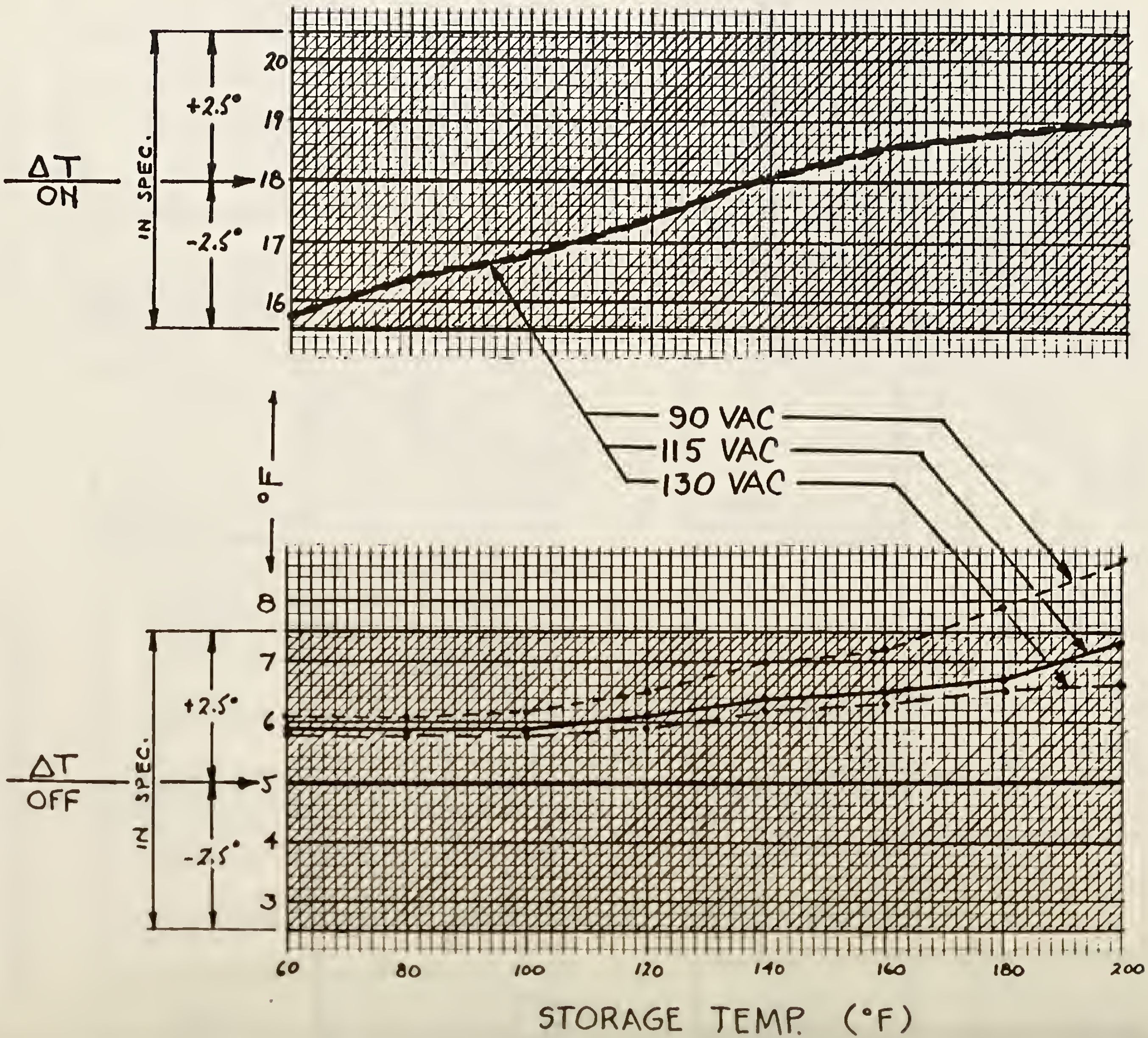
* DELTA T ON 18°F/DELTA T OFF 5°F

** DELTA T ON 9°F/Delta T OFF 4°F
Accuracy not specified by manufacturer

Figure 5

OPERATING CHARACTERISTICS AT VARYING VOLTAGES (DELTA T "ON" AND "OFF")

UNIT IIa



presently available.

Conclusions

Data collected using the test procedures described in this section, when analyzed in conjunction with baseline data seem to adequately characterize the CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF"). It is recommended, however, that methods which quantify response differences be studied to establish the most appropriate means for expressing these differences.

TEST 9 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION)

Purpose

This test is intended to characterize the controller's recirculating freeze protection response to line voltage fluctuation.

Test Conditions

This test is conducted in a manner identical to the tests described under TEST 2 - RECIRCULATING FREEZE PROTECTION with data taken at 20°F storage increments. Where TEST 2 - RECIRCULATING FREEZE PROTECTION was conducted with the controller operating at its nominal input voltage of 115 VAC, these tests are run with the electrical input to the controller at both the low and high voltage limits specified by the manufacturer. For purposes of this report, the variac supplying the power input to the controller was first set and maintained at 90 VAC and the RECIRCULATING FREEZE PROTECTION tests conducted. The variac was then reset to 130 VAC and the tests rerun. A separate voltmeter was used to verify the input voltage and the tests were conducted at a room ambient temperature of approximately 70°F.

Separate tests were conducted using the three identical controllers (units IA, IB, and IC) and in the 18/5 mode (IIa) and the 9/4 mode (IIb) using the single controller procured from a second source.

As described under TEST 2 - RECIRCULATING FREEZE PROTECTION, this test may be conducted separately or, for convenience, may be conducted in conjunction with TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF").

Procedure

1. All tests are conducted using the nominal temperature/resistance table provided by the controller manufacturer for the sensors recommended for use with his controller.
2. Using a variac or another adjustable voltage device, provide input power to the controller at the specified low voltage tolerance and maintain this voltage throughout the test.
3. Conduct TEST 9 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION) following the procedure detailed for TEST 2 - RECIRCULATING FREEZE PROTECTION.
4. Repeat step 3 after resetting the variac or other adjustable voltage device to the manufacturer's high voltage tolerance specification.

Results

The data for TEST 9 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION) are shown in Tables 37 through 40. Tables 37 and 38 present the test data for identical units IA, IB, and IC

at 90 VAC and 130 VAC respectively. Tables 39 and 40 show the test data for the single unit procured from a second source and tested in the 18/5 mode (IIa) and the 9/4 mode (IIb) at 90 VAC and 130 VAC.

The data for TEST 9 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION) for the three identical units tested (IA, IB, and IC) at both 90 VAC and 130 VAC (Tables 37 and 38) were compared to the data from TEST 2 - RECIRCULATING FREEZE PROTECTION conducted for these units at a nominal operating voltage of 115 VAC (Tables 6, 7, and 8). Although through an oversight, no data were collected for unit IB operating at 130 VAC, an inspection of the data collected for the other tests reveals that the activation temperature (PUMP "ON") varies no more than 0.3°F for all tested operating voltages. The temperature variation for the PUMP "OFF" signal is greater and the difference is especially apparent during the 90 VAC tests.

A similar comparison was made for unit IIa and IIb. The TEST 9 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION) data at 90 VAC and 130 VAC (Tables 39 and 40) and the baseline TEST 2 - RECIRCULATING FREEZE PROTECTION data (Table 9 and 10) show a response variance of no more than 0.1°F at all operating voltages. Although no definition for expressing accuracy has been established (see TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF"), the results indicate that the unit in each operating mode (IIa and IIb) is very insensitive to line voltage for RECIRCULATING FREEZE PROTECTION in the 90 VAC to 130 VAC range. The same unit did not perform as well in the RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND

Table 37

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION* (RECIRCULATING FREEZE PROTECTION)

90 VAC

UNITS IA, IB, IC

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IA 20/5	60		40.2				54.4
	80		40.2				53.7
	100		40.2				52.8
	120		40.2				51.9
	140		40.2				51.1
	160		40.2				50.4
	180		40.1				49.8
	200		40.1				49.3
IB 20/5	60		39.8				53.2
	80		39.8				52.5
	100		39.8				51.7
	120		39.8				50.9
	140		39.8				50.1
	160		39.8				49.4
	180		39.7				48.8
	200		39.7				48.4
IC 20/5	60		39.8				50.5
	80		39.7				49.0
	100		39.7				48.2
	120		39.7				47.7
	140		39.6				47.3
	160		39.6				47.1
	180		39.6				47.0
	200		39.6				46.9

* Test run concurrently with CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 38

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION* (RECIRCULATING FREEZE PROTECTION)

130 VAC

UNITS IA, IB, IC

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IA 20/5	60		40.3				53.9
	80		40.3				53.2
	100		40.3				52.4
	120		40.3				51.5
	140		40.3				50.7
	160		40.2				50.0
	180		40.2				49.4
	200		40.2				48.9
IB 20/5	60	NO DATA COLLECTED					
	80						
	100						
	120						
	140						
	160						
	180						
	200						
IC 20/5	60		39.8				50.1
	80		39.8				48.7
	100		39.8				47.8
	120		39.8				47.4
	140		39.7				47.1
	160		39.7				46.9
	180		39.7				46.7
	200		39.7				46.6

* Test run concurrently with CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")

** Accuracy specified by manufacturer - Freeze protection ON - 40° ±2°F
Freeze protection OFF - 44° ±2°F

Table 39

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION* (RECIRCULATING FREEZE PROTECTION)

90 VAC

UNITS IIa, IIb

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IIa 18/5	60		41.7			45.6	
	80		41.8			45.2	
	100		41.9			45.0	
	120		42.0			44.9	
	140		42.0			44.8	
	160		42.0			44.8	
	180		42.1			44.8	
	200		42.1			44.7	
IIb 9/45	60		41.7			45.6	
	80		41.8			45.2	
	100		41.9			45.0	
	120		42.0			44.9	
	140		42.0			44.8	
	160		42.0			44.8	
	180		42.1			44.7	
	200		42.1			44.7	

* Test run concurrently with CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

Table 40

CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION* (RECIRCULATING FREEZE PROTECTION)

130 VAC

UNITS IIa, IIb

Unit	Storage Temp Setting	Freeze Protection ON (Collector Temp)			Freeze Protection OFF (Collector Temp)		
		Outside Spec. (Low)	In Spec.**	Outside Spec. (High)	Outside Spec. (Low)	In Spec.**	Outside Spec. (High)
	°F	<38°F	40°±2°F	>42°F	<42°F	44°±2°F	>46°F
IIa 18/5	60		41.7			45.8	
	80		41.8			45.4	
	100		41.9			45.2	
	120		42.0			45.0	
	140		42.0			45.0	
	160		42.1			44.9	
	180		42.1			44.9	
	200		42.1			44.9	
IIb 9/45	60		41.7			45.8	
	80		41.8			45.4	
	100		41.9			45.2	
	120		42.0			45.0	
	140		42.0			45.0	
	160		42.0			44.9	
	180		42.1			44.9	
	200		42.1			44.9	

* Test run concurrently with CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF")

** Accuracy assumed the same as Units IA, IB, and IC.

"OFF") especially in the highest temperatures at 90 VAC. However, these results are not inconsistent in that TEST 2 - RECIRCULATING FREEZE PROTECTION characterizes the controller's response at relatively low collector operating temperatures although the storage set point was varied over the entire temperature range.

Conclusions

Data collected at specified voltage limits using the test procedures described in this section, when analyzed with comparable data collected at the control nominal operating voltage, seem to adequately characterize the CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (RECIRCULATING FREEZE PROTECTION). The lack of an appropriate means to express the degree of difference in test results, as described in TEST 8 - CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION (DELTA T "ON" AND "OFF") also applies to these tests.

IV. GENERAL CONCLUSIONS

In reviewing the overall results of the tests conducted, it appears that the controller's response at ambient conditions can be reasonably characterized using the tests described herein. This is especially true sinces the controllers response to various inputs is observed to vary gradually with no abrupt changes, breaks, transitions, or spikes. The adequacy of these tests can only be evaluated through the additional testing of a broader spectrum of controller types and also must be evaluated in a context of the complete test package including the additional tests to be developed as outlined in the overall test plan. (See Appendix.) However, the tests detailed above should form a solid basis for controller evaluation. In addition, the use of decade resistance boxes proved to be an effective method for testing controller performance.

Specifically, for units tested using the accuracies specified or assumed, the following conclusions are offered after reviewing the test data:

1. All units tested failed to meet all specified or assumed specifications.
2. In the DELTA T "ON" AND "OFF" mode, the single unit tested in both the 18/5 and 9/4 option (IIa, IIb) performed better than any of the three identical units tested (IA, IB, IC). Of the three identical units tested, the IB unit was the least accurate.
3. In the RECIRCULATING FREEZE PROTECTION mode, Units IA, IB, and IC were all outside-of-specification for freeze protection "OFF". Unit IIa was in specification for this function while Unit IIb was slightly out-of-specification at the high temperature settings for freeze protection "ON".

4. All units tested were out-of-specification in varying amounts when tested for CONTROLLER RESPONSE TO SENSOR TOLERANCE for both DELTA T "ON" AND "OFF" and RECIRCULATING FREEZE PROTECTION.
5. All units performed poorly in the CONTROLLER RESPONSE TO STORAGE HIGH TEMPERATURE LIMIT except Unit IIa, IIb which was in-specification for STORAGE HIGH TEMPERATURE (PUMP ON).
6. When Units IA, IB, and IC were operated with an auxiliary sensor to detect freeze conditions, the DELTA T "ON" AND "OFF" functions changed little, however, the RECIRCULATING FREEZE PROTECTION response shifted from completely out-of-specification for freeze protection "OFF" to in-specification for most storage temperature settings.
7. The PUMP "OFF" BELOW 80°F function performed in-specification for Unit IIa, IIb.
8. For line voltage range tested, Units IA, IB, and IC were not sensitive to line voltage variation; however, Unit IIa, IIb drifted out-of-specification at low operating voltages for higher storage temperature settings in the DELTA T "ON" AND "OFF" mode.

It should be noted that the conclusions listed above would vary if different specification limits were used. In this regard, it is emphasized that a complete specification description be provided for each type of controller so that the results can be adequately interpreted. Also, it is suggested that the specification vary with function with a tighter specification prescribed for the important DELTA T "ON" AND "OFF" function and perhaps a less stringent specification for the secondary features such as PUMP "OFF" BELOW 80°F. In addition, the sensor tolerance range should be integrated with the controller's tolerance range to assure adequate

function over all ranges of operation for all sensors regardless of location within the solar energy system. Finally, some means to express differences in CONTROLLER RESPONSE TO LINE VOLTAGE FLUCTUATION needs to be developed.

V. REFERENCES

[1] An Analysis of the Effects of Active Solar Energy Sensor Degradation on Solar Performance; R.B. Farrington and W. Short; SERI/TR-253-2185; Solar Energy Research Institute; July 1984.

[2] A Summary and Assessment of Historical Reliability and Maintainability Data for Solar Hot Water and Space Conditioning Systems; G.J. Jorgensen; SERI/TR-253-2120; Solar Energy Research Institute, May 1984.

[3] Evaluation and Laboratory Testing of Solar Domestic Hot Water Control Systems; R.B. Farrington and D. Myers; SERI/TR-254-1805; Solar Energy Research Institute; February 1983.

[4] Survey of Failure Modes from 122 Residential Solar Water Heaters; Prepared by ESG, Inc., Atlanta Georgia for SERI; SERI/STR-253-2531; Solar Energy Research Institute; October 1984.

[5] Research Priorities for Improving the Effectiveness of Active Solar Hot Water and Space Conditioning Systems; NBSIR 84-2980; R. Dikkers, W.J. Kennish, C.B. Winn, and W. Huston; National Bureau of Standards; December 1984.

APPENDIX

A previous version of this Test Plan, which constitutes the Appendix of this document, was distributed to approximately 30 individuals for review and comment. These individuals encompass a broad spectrum of the solar energy community and include controller manufacturers, solar system integrators, universities, national laboratories, government agencies, and others with interests in solar energy systems. The Test Plan has been updated to reflect comments received and generally incorporates experience gained by the testing results reported in this document.

TEST PLAN

FOR

DIFFERENTIAL TEMPERATURE CONTROLLERS

USED IN

SOLAR ENERGY SYSTEMS

TABLE OF CONTENTS

TEST PLAN FOR DIFFERENTIAL TEMPERATURE CONTROLLERS USED IN SOLAR ENERGY SYSTEMS

1.0 GENERAL

1.1 Nomenclature

1.1.1 The term "controller" as used herein is intended to mean differential temperature controller (DTC) used in active solar energy systems.

1.2 Scope

1.2.1 The tests identified herein are intended to provide a recognized test method to verify, or to form the basis for, the manufacturer's statements contained in his specification literature regarding controller performance including such statements addressing accuracy, stability, environmental application, etc.

1.2.2 Sensors intended for use with the controller are considered part of this scope only to the extent that they constitute the input signals which cause the controller to activate or deactivate.

1.2.3 These tests are generally not intended to predict the effects of component aging or long term repeated cycling on controller performance.

1.2.4 These tests are generally not intended to be safety tests evaluating such hazards as potential for fire, high temperature injury, electrical shock, short

circuit, etc. Safety tests are covered in the Underwriter's Laboratory (UL) Standards for Safety [1, 2, 3] and the Canadian Standards Association (CSA) Safety Standard [4]. Some portions of these safety tests, however, may be incorporated in the performance test procedures if they fall within the scope of 1.2.1 above.

1.2.5 The tests identified herein are intended to cover all controller features, except as described below in 1.2.6. Tests when conducted would be controller specific with the individual controller functions and configuration determining tests to be included or omitted. Definitive features, ranges, tolerances, etc. not included in the manufacturer's specification literature generally would not be tested. However, an alternative to this approach is to test each controller feature and compare the results to a default (predetermined) level if no specification data are provided.

1.2.6 The tests identified herein are intended to cover differential temperature controllers including controllers which also incorporate other features commonly used to control active solar energy systems and designated herein as "on/off" controllers. Omitted from this preliminary scope are proportional controllers, complex programmable controllers designed for large solar installations, and those controllers

performing such functions intended to monitor direct solar insolation associated with solar tracking systems. (Note: Test procedures for proportional controllers could be added to the scope of this program or could be developed subsequently).

1.3 Identification of Features to be Tested

1.3.1 A review has been conducted to characterize those types of controllers currently being marketed and to identify features available and performance parameters specified. These data were abstracted from the 1984 Energy Products Specification Guide [5] and a summary for forty-five (45) controllers is shown in Fig. 1 (page A-30). The summary includes thirty-six (36) "on/off" controllers and nine proportional controllers detailing the property identified, the number of controllers specifying the property, and the overall range of extremes for that property. Where the extreme ranges specified are atypical, a more representative range is included. These ranges will be referenced below under each specific test procedure to assure that when a definitive test procedure is developed the procedure is adequate in range to accommodate units being marketed.

1.4 Sensor Interface

1.4.1 Although the thrust of these functional test procedures is focused on the solar controller, the control system

is not complete without the sensing devices which provide the input signals to allow the controller to determine when to start or stop the circulating pump, activate a freeze protection strategy, or protect the system from excessive temperature. These sensors are the "front-end" of the control system and must interface precisely with the controller for effective operation. The types of sensors available for temperature input to the controller are: Resistance Temperature Detectors (RTDs), Thermistors, Thermocouples, and Integrated Circuit Temperature Sensors. Each is described below, however, the RTDs and the Thermistors are presently the most commonly used devices for solar control application.

1.4.1.1 Resistance Temperature Detectors (RTDs) - These devices typically use platinum, copper, or nickel wire; increase in resistance with increased temperature; and generally have a linear resistance/temperature curve for solar application. A typical platinum RTD with a 100 ohm nominal resistance may vary as much as 20 ohms over its operating range [6].

1.4.1.2 Thermistors - These devices are generally composed of sintered particles of metal oxides bound between two conductive surfaces; decrease in resistance with increased temperature; have a non-linear resistance/temperature curve; have a high

internal resistance (1,000 - 35,000 ohms); and often experience a change in resistance over time if improperly used [6]. Two common thermistor types used in solar applications are (1) the 3K thermistor (3000 ohms at 77°F [25°C]) and (2) the 10K thermistor (10,000 ohms at 77°F [25°C]).

1.4.1.3 Thermocouples - These devices are formed by welding, soldering, or pressing together two dissimilar metals and require a reference junction of known temperature for operation; provide an increasing voltage output with increasing temperature; and can be considered to have a linear temperature/voltage curve within the solar application range. A typical thermocouple output is measured in milli-volts [6].

1.4.1.4 Integrated Circuit Temperature Sensors - These devices are integrated circuit chips often in a configuration resembling a transistor; have an output proportional to the temperature measured; are generally linear but require additional electronic components for operation [6].

1.4.2 Since the operation of the controller depends on the input signals received from the sensors, there are several strategies that can be used for controller testing. One consists of system tests which use the actual sensing devices for input while others consist of using a simulated input to activate the controller.

Each is discussed below.

1.4.2.1 Controller Tests Using Sensor Input - These tests are performed using the sensor provided or recommended by the manufacturer. The controller's function would be activated by inserting each sensor in a controlled temperature liquid bath or oven. Each functional point tested would require changing the bath or oven temperature and allowing the sensor to stabilize at the new temperature. Tests using this method were performed by Wyle Laboratories [7] who reported the test method unusable because of the difficulty in gradually changing temperatures to activate the controller functions. These changing temperatures require precise temperature and power controls on the baths and despite these controls, there were problems with temperature gradients and differences in thermal mass of the sensors and the calibrated temperature measuring device. The time required to measure each data point was also reported as excessive since the temperature of the bath had to be changed very slowly.

In addition to the above consideration, the tests, if successful, would only be valid for that specific sensor/controller combination. If after installation a sensor failed and an exact replacement were unavilable, a new sensor with

different characteristics could trigger the controller at uncertain activation temperatures. Also, if aging tests are needed and later developed for the sensor/controller system, the aging and drift of the sensors should be separated so as not to obscure the aging effects of the controller components themselves. Finally, there would be little impetus for the industry to produce interchangeable sensors and controllers to provide the user with maximum flexibility regarding product application and costs.

1.4.2.2 Controller Tests Using Simulated Input - As a substitute procedure for testing controllers, Wyle Laboratories used decade resistance substitution boxes to simulate the sensors [7]. This method was also used by SERI in their evaluation of Solar Domestic Hot Water Control Systems [8] and they reported that they obtained good repeatability and were able to perform their experiments in a fraction of the time that would have been required using the controller's associated sensors and a temperature bath or oven. However, the test repeatability should be studied to determine the criteria for determining the number of times the parameters should be varied for statistical confidence.

Since this method essentially separates the controller performance from that of the sensor, some methodology must be used to determine the resistor/temperature curve to be used in controller testing. Effectively, three alternatives are available: (1) test the associated sensors separately in a temperature bath or oven and develop specific resistance/temperature curves for use with each individual controller; (2) use the specific resistance/temperature curves provided by the sensor manufacturer, or (3) develop a suitable standardized resistance/temperature curve for each type of sensor (3K, 10K, RTD, etc.).

Of the three alternatives identified above, the approach using the standardized resistance/temperature curve seems most attractive. Using such a method would simplify controller testing and could provide the basis for an independent standard for sensor performance. Lacking such a standard, a correlation methodology would need to be developed to interface the sensor which did not follow the "standard" resistance/temperature curve.

1.5 Accuracy Representation

1.5.1 As summarized in Fig. 1 the representation of controller tolerance varied considerably. A sampling is listed below:

(a) ±2.5°F

(b) ±2°F over range

(c) ±0.4°F over a 0° to 70°F range

(d) 10 mV/°F

(e) ±2%

(f) line voltage variation of 10% results in a ±1/2°F differential change

(g) ±2°F "on"; - 0.5° to +1.0°F "off"

These representations of controller tolerance could be very confusing or misleading to the purchaser of this type of equipment. The development of test procedures for controllers can provide an opportunity to also standardize the tolerance representation so that tested controllers could be characterized by specification in an consistent manner. A representation of controller tolerance could provide a tight tolerance where required; i.e., differential control of ±1°F over a 30°F to 150°F range, and perhaps a lesser requirement for the high limit cut-off; i.e., (180° ±5°F). Also, a specific tolerance based on degrees (i.e. ±2°F) would seem to be more desirable than a tolerance based on percent (i.e. ±2%) to avoid changing functional characteristics over a large operating range.

1.6 The test procedures identified in the following sections are generally described in sequence order so that the potentially destructive tests are performed last. A more definitive sequence

will be developed after additional experience is gained and the test procedures refined.

2.0 PRE-TEST INSPECTION

2.1 Purpose - To inspect the unit to be tested for obvious flaws or deficiency in quality which will prevent the unit from functioning and to form a baseline for post-test inspections.

2.1.1 Each controller should be inspected prior to testing to note the physical condition of the unit. This procedure was proposed by both Wyle [7] and SERI [8] to detect such manufacturing or design defects as cracks, abnormal bends, signs of corrosion, mislabled wires, poorly mounted components, etc. The results of such visual inspection should be documented as an aid to characterizing the cause of subsequent failures and as the basis for evaluating any changes to the controller components resulting from the tests performed.

3.0 FUNCTIONAL TESTS - (AMBIENT)

3.1 Purpose - To test controller output functions as a response to specified input signals at varying parameters with the controller operating at ambient conditions.

3.1.1 Non-adjustable Unit - These tests would be performed on controllers that are factory set and not intended to be field adjusted by the installer or user. If some controller functions are fixed and some adjustable, the fixed functions shall be tested as specified below and the adjustable functions as described in 3.1.2. (Note:

Test ranges indicated below are tentative and are based on the ranges shown in Fig. 1. Definitive test ranges will be developed, as appropriate, along with the development of the specific test procedure.)

3.1.1.1 Delta T "on" - This test shall be conducted by holding one sensor at a fixed temperature and varying the temperature of the other sensor until the controller delta T "on" output device (relay or switch) is activated. This test must be repeated over the operating range specified by the manufacturer at increments which will provide the data to characterize the controller's delta T "on" response. The form of the test might be as follows: Using a decade resistance substitution box, simulate and fix the storage temperature sensor and vary the collector sensor resistance until the output device is activated. Repeat with the storage simulated temperature varied at fixed intervals. The delta T "on" test range might be 8°F to 20°F (see Fig. 1) and the simulated storage temperature varied from 60°F to 200°F.

3.1.1.2 Delta T "off" - This test shall be conducted by holding one sensor at a fixed temperature and varying the temperature of the other sensor until the controller delta T "off" output device (relay or switch) is deactivated. This test must be repeated over the operating range specified by the

manufacturer at increments which will provide data to characterize the controller's delta T "off" response. This test might be conducted in conjunction with the delta T "on" tests (3.1.1.1) with the collector sensor resistance simulated by the decade resistance substitution box varied until the output device is deactivated. The delta T "off" test range might be 3 °F to 5 °F (see Fig. 1).

3.1.1.3 High Limit - This test shall be conducted by increasing the simulated temperature input to the high temperature sensor until the high limit output device is activated. The simulated temperature input would then be decreased until the output device is deactivated to determine the "deadband" of the device. In some controllers, the high temperature limit is activated by the collector sensor which is a component of the delta T "on" and "off" sensing system while in other controllers an independent bimetallic thermal switch is used [9]. The form of the test for all sensors except the bimetallic switch might be as follows: Using a decade resistance substitution box, simulate the high limit sensor and increment the equivalent resistance until the controller is activated (or deactivated, depending on controller output configuration). Repeat, decreasing the simulated temperature input in incremental steps

until the controller is deactivated (or activated). The test range for the high limit function might be 160°F to 212°F (see Fig. 1).

3.1.1.4 Low Limit (Freeze Protection) - This test shall be conducted by decreasing the simulated temperature input to the low limit (or freeze protection) sensors or thermal switches until the low limit output device is activated; and increasing the simulated temperature input until the device is deactivated. The form of the test would be similar to that described for the high limit test in 3.1.1.3. The test range for the low limit function might be in the 40°F - 45°F range (see Fig. 1).

3.1.1.5 Other Features (Non-Adjustable) - Tests shall be developed to evaluate other features specified in the manufacturer's literature. Such features may include time delay options, pump "off" below 80°F, etc. If appropriate, the operation of this feature will be evaluated to assess any changes to primary controller functions.

3.1.2 Adjustable Unit - These tests would be performed on controllers that are designed to be adjustable in the field by the installer or the user. Depending on controller design, the adjustments may be made over the adjustment range through the use of an adjustable potentiometer, incremental switch, or by resistor

substitution. If some controller functions are adjustable and some fixed, the adjustable functions shall be tested as specified below and the fixed functions as specified in 3.1.1.

3.1.2.1 Delta T "on" - These tests shall be conducted as described in 3.1.1.1 for the non-adjustable unit except they shall be repeated for various settings over the adjustment range. If the adjustable component is a variable potentiometer, tests might be run with the lowest delta T "on" setting and repeated for a number of increments over the adjustable range. If the adjustable component is a step switch or replaceable resistor, tests might be run at each switch setting or resistor replacement over the specified operating range. In addition, the delta T "off" tests and high and low limit tests may have to be repeated to assess the effect, if any, of changing the variable delta T "on" function on the other controller functions. Typical test ranges for the adjustable delta T "on" might be 9°F to 20°F (see Fig. 1). If appropriate, this test may be repeated for other adjustable feature settings to determine the effects of these varying settings on the delta T "on" operation.

3.1.2.2 Delta T "off" - These tests shall be conducted as described in 3.1.1.2 except they shall be repeated

for various settings over the adjustment range as described in 3.1.2.1. In addition, the delta T "on" tests and high and low limit tests may have to be repeated to assess the effect, if any, of changing the variable delta T "off" function on the other controller functions. Typical test ranges for the adjustable delta T "off" might be 1°F to 5°F (see Fig. 1). If appropriate, this test may be repeated for other adjustable feature settings to determine the affects of these varying settings on the delta T "off" operation.

3.1.2.3 High Limit - These tests shall be conducted as described in 3.1.1.3 except they shall be repeated for various settings over the adjustment range. To characterize the high limit on/off activation points of the controllers, the adjustable controller element will be set at its lowest temperature setting, the simulated temperature input increased until the controller output is activated, then decreased until deactivated. The test would be repeated by incrementally raising the high limit setting. The test range for the adjustable high limit function might be 160°F to 212°F (see Fig. 1).

3.1.2.4 Low Limit (Freeze Protection) - These tests shall be conducted as described in 3.1.1.3 except they shall be repeated for various settings over the

adjustment range to characterize the low limit (freeze protection) on/off activation points of the controller. The adjustable controller element will be set at its highest temperature setting, the simulated temperature input decreased until the controller output is activated, then increased until deactivated. The test would be repeated by incrementally lowering the low limit (freeze protection) setting. This test may be performed in conjunction with the delta T "on" and "off" test.

3.1.2.5 Other Features (Adjustable) - Tests shall be developed to evaluate other features specified in the manufacturer's literature. Such features may include time delay options, pump "off" below 80°F, etc. If appropriate, the operation of this feature will be evaluated over its entire adjustable range to assess and changes to primary controller functions.

4.0 CONTROLLER DISPLAY TESTS - (AMBIENT)

4.1 Purpose - To test controllers equipped with display readouts to determine the accuracy of indicated display to measured temperature (or delta temperature) and to test the operational characteristics of controllers equipped with switchable functional controls.

4.1.1 Of the controllers reviewed, 16 were equipped with a variety of displays and functional controls integral to

the controller and five others included features that allowed the display to be indicated on a unit that was hard-wired remotely from the controller (see Fig. 1). The displays included digital temperature readouts and delta T indications; analog meter readings; functional operational lights; and, operational selector mode switches. These tests are included because the assumption must be made that the installer or user will depend on the accuracy of the indicated reading for assessing operational conditions.

4.1.2 The controller display tests shall generally be conducted, on controllers so equipped, concurrently with the functional tests described above in 3.0. In effect, the simulated sensor input setting required to activate the controller output device (relay or solid state switch) should register on the display output in a manner consistent with the stated accuracy of the readout. In addition, if the display is intended to continually indicate (or indicate on demand) a sensor temperature (or a delta temperature), the simulated sensor resistance should cause a correspondingly accurate temperature indication on the display. Because display configurations are unique to individual manufacturer's controllers, general provisions and guidelines may be required.

4.1.3 Individual or special tests of functional indicating lights or operational selector mode switches may not be

necessary, if, in performing the functional tests described in 3.0 these display modes or switch settings are intrinsic to the tests being performed and can be observed during the conduct of the performance tests.

5.0 INPUT RESISTANCE TO ELECTROMAGNETIC INTERFERENCE (EMI) TEST-(AMBIENT)

5.1 Purpose - To test the controller's response to Electromagnetic Interference (EMI) picked-up by the sensor leads causing unwanted controller activation.

5.1.1 Electronic signals emitted from power sources, motors, communication equipment, etc. can induce "noise" signals in the sensor leads causing unwanted controller activation. This is especially true if the sensor leads exceed 100 ft. although shorter leads under certain conditions can also exhibit this property. The term Electromagnetic Interference (EMI) will be used herein to describe this effect as present usage favors this more general EMI term in place of the older Radio Frequency Interference (RFI) term [10].

5.1.2 Current practice for installing sensor leads can reduce the effects of EMI on the controller. This includes twisting the sensor leads together at approximately one twist per inch, using shielded and grounded cable, routing of wires away from EMI sources such as power lines and motors, and, when necessary to cross power lines, by running the sensor leads over the power lines at right angles. Test procedures will not be developed

to verify the effectiveness of these techniques since they are external to the controller unit itself.

5.1.3 The thrust of this test procedure will be focused on controller units that specify that they have intrinsic EMI protection through internal EMI filtering or other special circuitry. Tests could be conducted using various length sensor leads and varying sensor resistance simulations. Line-voltage (115V) power lines could be run in parallel with and in close proximity to the sensor leads and any unwanted controller output monitored. Other tests might include an arc discharge or an unfiltered motor operating in close proximity to the sensor leads. It should be noted that little research has been documented in the EMI area as applied to differential controllers used in solar energy systems.

5.1.4 The tests proposed herein for EMI relates solely to the susceptibility of the controller to EMI input through the sensor leads. This should not be confused with EMI signals produced by the controller itself which would affect other electronic devices near the controller such as radios, televisions, or communication equipment. These signals are produced by certain proportional controllers and others using electrical switching devices (as opposed to mechanical relay switching devices) as part of the controller circuitry.

6.0 ELECTROMAGNETIC INTERFERENCE (EMI) RADIATION TESTS - (AMBIENT)

6.1 Purpose - To test the generation of Electromagnetic Interference (EMI) produced by the controller.

6.1.1 The controller's electronic circuits under certain circumstances can produce Electromagnetic Interference (EMI) which may be transmitted to radio, television, telephone, and other such devices to cause a noise, buzz, distortion or other unwanted signal change. Of particular concern are those controllers that use solid state switching which can produce EMI if operated in the delayed firing (phase angle) switching modes [9, 11]. The development of a test procedure for EMI Radiation Tests will require further study.

6.1.2 This test may be required only for proportional controllers, however, other on/off controllers may also emit EMI radiation if their power supplies or other electrical circuits are not designed properly. If, after laboratory study, EMI Radiation is found not to be a problem with on/off controllers, this test requirement would be dropped. Never-the-less, if the scope of this effort is expanded to include proportional controllers, an EMI Radiation test procedure, at least for proportional controllers, should be developed.

7.0 SENSITIVITY TO LINE VOLTAGE FLUCTUATION - (AMBIENT)

7.1 Purpose - To test the controller's operational stability during line voltage fluctution conditions.

7.1.1 Differential controllers currently being produced use solid state circuitry for their power supplies, logic circuits, amplifiers, etc. These solid state circuits are sensitive to input voltage changes unless compensated for by additional stabilizing circuitry. This test would verify the controller response at varying input voltage conditions. The test range for line voltage fluctuation might be 105 to 130 VAC; and 210 to 260 VAC (see Fig. 1). Controllers having the capability for multi- voltage operation would be tested in each voltage range.

7.1.2 The controller would be connected to a regulated adjustable power source. The power source would be adjusted for the maximum voltage specified for the controller under test and the following tests conducted:

a. Functional Tests as described in 3.0 including:

1. Delta T "on"
2. Delta T "off"
3. High Limit
4. Low Limit

b. Controller Display Tests as described in section 4.0.

The power supply shall then be readjusted for the minimum voltage specified for the controller and the above tests repeated.

7.1.3 All other tests, described herein, shall be conducted with the controller being supplied from the locally available commercial power source.

8.0 SENSITIVITY TO HIGH-VOLTAGE SURGE - (AMBIENT)

8.1 Purpose - To test the controller's susceptibility to damage induced by high-voltage surges or spikes.

8.1.1 The test procedures would be based on UL 873 [3], Section 38, Dielectric Voltage Withstand, with modifications to make the test directly applicable to differential controllers.

8.1.2 Controllers tested for sensitivity to high-voltage surge shall be visually inspected for physical changes as described in 12.0.

8.1.3 After the sensitivity to high-voltage surge test is conducted and the unit visually inspected, the controller shall be retested at ambient by conducting all the functional tests described herein in 3.0 and 4.0 to determine any operational changes resulting from the high-voltage surge test.

8.1.4 The above tests would not be performed if the manufacturer makes no comment in his specifications

regarding his unit's capability to withstand high-voltage surges.

9.0 VIBRATION TESTS - (AMBIENT)

9.1 Purpose - To test the ability of the controller, if designed to be pump mounted, to operate under vibrational stress conditions.

9.1.1 Of the controllers reviewed, five controller specifications indicated that they are designed to be mounted on pumps, valves, or storage tanks (see Fig. 1). These tests address pump mounted controllers and their ability to operate under vibrational test conditions. SERI, [8] reported that they conducted research to determine the actual spectral distribution of vibrational energy and the total vibrational energy generated in the operation of actual pumps used in solar applications. The results were used to test a controller using a simulation of the operational pump vibration using a laboratory shaker as the exciter. SERI concluded that the tested controller continued to operate without failure or significant deviation in performance. However, no firm conclusions could be drawn without additional testing over a longer period of time to accumulate more data and experience.

9.1.2 Test procedures will be developed using the SERI experience as a starting point. Because of the complexity of this type of test procedure and the relatively small number of pump mounted controllers marketed, this section may be developed after the

completion of the remainder of the controller test procedure and added at a future date.

9.1.3 Controllers subjected to vibration testing shall be visually inspected for physical changes as described in 12.0.

9.1.4 After the vibration tests are conducted and the unit visually inspected, the controller shall be retested at ambient by conducting all the functional tests described herein in 3.0 and 4.0 to determine any operational changes resulting from the vibrational tests.

10.0 STABILITY WITH CHANGING INDOOR ENVIRONMENTAL CONDITIONS

10.1 Purpose - To test the controller's operational stability over the range of indoor environmental temperatures and humidities specified by the manufacturer.

10.1.1 Controller tests performed at ambient temperature will be repeated at the specified high and low ambient temperature using an appropriate environmental chamber. Humidity tests will also be conducted concurrently at the relative humidity extremes specified. If humidity extremes are not specified, tests will be conducted at a default predetermined relative humidity condition. Temperature and humidity tests may also be conducted at intermediate points between the extremes specified, if appropriate. The test range for ambient temperature

and humidity might be 32°F to 120°F at a range of 5 to 95% relative humidity (see Fig. 1).

10.1.2 The controller shall be placed in the appropriate environmental chamber and exposed to the test temperature and humidity. A "soaking" period may be required to allow the controller to stabilize at the test condition before beginning the functional tests. Controllers tested by SERI [8] were environmentally "soaked" for at least 72 hours while Wyle [7] used a seven day (168 hour) soak period. Wyle also subjected controllers to a ten cycle extreme temperature preconditioning before environmental testing.

10.1.3 With the controller in the environmental chamber and environmentally stabilized, the following tests shall be conducted.

a. Functional Tests as described in 3.0 including:

   1. Delta T "on"
   2. Delta T "off"
   3. High Limit
   4. Low Limit

b. Controller Display Tests as described in 4.0.

10.1.4 In addition, consideration shall be given to conducting the following tests under high and low ambient temperature and humidity if operational experience or general testing shows that controller sensitivity is degraded during extreme indoor environmental conditions.

a. Sensitivity to Line Voltage Fluctuation as described in 7.0.

b. Sensitivity to High-Voltage Surge as described in 8.0.

10.1.5 After all of the environmental tests are completed, the controller shall be allowed to return to ambient conditions and stabilize and be free from any accumulated moisture resulting from the high humidity tests. (In their environmental testing report, Wyle [7] provides for a 24 hr. stability period.) The controller is then retested at ambient by conducting all the tests described herein in 3.0 and 4.0 to determine any operational changes resulting from these environmental tests.

10.1.6 Controllers tested for stability with changing indoor environmental conditions shall be visually inspected for physical changes as described in 12.0.

11.0 OUTDOOR ENVIRONMENTAL TESTS

11.1 Purpose - To test those controllers that are intended for uses under environmental conditions, other than indoor ambient, as specified by the manufacturer.

11.1.1 Fig. 1 indicates four controllers designed for extraordinary environmental conditions including: rain tight, water tight, and water proof construction. These environmental operating conditions would have to be defined carefully before an adequate test procedure

is developed. Several tests have been identified and others will have to be researched to develop appropriate test procedures applicable to solar differential controllers.

11.1.2 Tests identified include Rain Tests (UL 429 [12]) and Salt Spray (Fog) Testing (ANSI/ASTM B 117-73 [13]). If existing test methods cannot be adopted or are inadequate for the purposes intended, new test methods may have to be developed. Other outdoor environmental tests might include dust, ice, and extreme high and low outdoor temperature tests similar to the high and low indoor temperature environmental tests described in 10.0. Consideration shall also be given to conducting the outdoor and indoor high and low temperature tests concurrently if the specified ranges are compatible.

11.1.2 After outdoor environment testing, the controller units shall be visually inspected for physical changes as described in 12.0 and retested at ambient for functional operation as described in 3.0 and 4.0.

12.0 POST-TEST INSPECTIONS

12.1 Purpose - To inspect the controller after a severe, potentially damaging test to determine any permanent damage to the controller and to aid in assessing future controller performance.

12.1.1 A post-test visual inspection shall be made of the controller to determine changes in component condition such as cracks or corrosion, which would adversely

effect the long term operation of the controller. This inspection would use the information documented during the Pre-Test Inspection (2.0) as a baseline for comparison. It should be noted that this assessment of long term operation is not meant to be a definitive determination of the long term controller reliability or operational life expectation.

12.1.2 Post-test visual inspection shall be performed after the following tests are complete.

a. Sensitivity to Line Voltage (7.0)

b. Sensitivity to High Voltage Surge (8.0)

c. Vibration Tests (9.0)

d. Stability With Changing Indoor Environmental Conditions (10.0)

e. Outdoor Environmental Test (11.0)

REFERENCES

[1] Underwriters Laboratory - Standard for Safety; UL 353; Limit Controls.

[2] Underwriters Laboratory - Standard for Safety; UL 508; Industrial Control Equipment.

[3] Underwriters Laboratory - Standard for Safety; UL 873; Temperature Indicating and Regulating Equipment.

[4] Canadian Standards Association; CSA Standard C22.2 No. 24-1981; Temperature Indicating and Regulating Equipment.

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[10] Noise Reduction Techniques in Electronic Systems; H.W. Ott; John Wiley and Sons; 1976.

[11] National Electrical Manufacturers Association (NEMA); Standard 11-11-1976.

[12] Underwriters Laboratory - Standard for Safety; UL 429; Electrically Operated Valves.

[13] American National Standard/American Society for Testing Materials; ANSI/ASTM B117-73 (Reapproved 1979); Standard Method of Salt Spray (Fog) Testing.

Figure 1

RANGE OF CONTROLLER SPECIFICATIONS

PROPERTY	ON/OFF CONTROLLER		PROPORTIONAL CONTROLLER	
	TOTAL NO. 36 NUMBER SPECIFYING PROPERTY	OVERALL RANGE [TYPICAL RANGE]	TOTAL NO. 9 NUMBER SPECIFYING PROPERTY	OVERALL RANGE [TYPICAL RANGE]
NON-ADJUSTABLE				
ΔT "ON"	26	4.5°F - 40°F [8°F - 20°F]	5	20°F (Full On)
ΔT "OFF"	26	1°F - 20°F [3°F - 5°F]	5	3.5°F (Full Off)
HIGH LIMIT	7	160°F - 240°F [160°F - 212°F]	3	160°F
LOW LIMIT	9	35°F - 55°F [40°F - 45°F]	3	Unspecified
ADJUSTABLE				
ΔT "ON" "OFF"	8	5°F - 27°F [9°F - 20°F] 0°F - 7°F [1°F - 5°F]	2	10°F between min. and max. output
ΔT "ON" ONLY	3	0°F - 20°F [9°F - 20°F]	2	5°F - 20°F (Min Fan Speed Adjust; Max Speed 20°F Higher)
ΔT "OFF" ONLY	0	Unspecified	1	Field Adjust Turn-Off Selectable at 7°; 3°F
HIGH LIMIT	14	60°F - 240°F [160°F - 212°F]	2	Unspecified
LOW LIMIT	6	Unspecified	1	Unspecified

PROPERTY	ON/OFF CONTROLLER		PROPORTIONAL CONTROLLER	
	TOTAL NO. 36 NUMBER SPECIFYING PROPERTY	OVERALL RANGE [TYPICAL RANGE]	TOTAL NO. 9 NUMBER SPECIFYING PROPERTY	OVERALL RANGE [TYPICAL RANGE]
SENSITIVITY	36	±2.5°F; ±2°F over range; ±0.4°F over a 0° to 70°C range; 10 mV/°F to 18 mV/°F; ±10%; line voltage variation of 10% results in ±1/2°F differential change; ±2°F "on", - 0.5° to 1.0°F "Off" [±1°F - ±2°F]	9	±2°F; ±2°F "On", -0.5°F to 1.0°F "Off"
SENSOR TYPE	7 5 4 5	Thermistor (unspecified) 10K Thermistor 3K Thermistor Wire (resistance temperature detectors)	1 1	Thermistor (unspecified) Wire (resistance temperature detectors)
CONTROLLER AMBIENT TEMPERATURE	14	0°F to 170°F [32°F - 120°F]	6	32°F to 150°F
CONTROLLER AMBIENT RELATIVE HUMIDITY	1	5 - 95% RH		95% RH non-condensing
MOUNTING	5	Pump; valve; on storage tank	2	Pump; duct
WATER PROOF/ WEATHERIZED	4	Rain tight; water tight; water proof	0	-
DISPLAY/CONTROLS	16	Panel lights; temperature display, ΔT; digital, meter; operational mode	6	Panel lights; temperature display ΔT; operational moded
REMOTE DISPLAY	5	Temperature; operational mode	1	Operational mode

PROPERTY	ON/OFF CONTROLLER		PROPORTIONAL CONTROLLER	
	TOTAL NO. 36 NUMBER SPECIFYING PROPERTY	OVERALL RANGE [TYPICAL RANGE]	TOTAL NO. 9 NUMBER SPECIFYING PROPERTY	OVERALL RANGE [TYPICAL.RANGE]
INPUT VOLTAGE	34	105 - 130 VAC	7	117 - 120 VAC
	10	210 - 260 VAC	1	220 VAC
	4	24 VAC	1	24 VAC
INPUT POWER	16	2 - 10 Watts	4	2.5 - 40 Watts
	3	.09 - 15 Amps		[2.5 - 7 Watts]
OPERATING FREQUENCY	4	60 Hz	2	60 Hz
	4	50/60 Hz	1	50/60 Hz
	1	50 Hz		
OUTPUT TYPE	28	Relay	-	Relay
	7	Solid State	9	Solid State
NUMBER OF OUTPUTS	7	1 - 5	2	3 - 4
		[1 - 2]		
SWITCHING VOLTAGE	13	110 - 120 VAC	1	120 VAC
	4	220 - 240 VAC		
	4	12 - 24 VAC	1	24 VAC
SWITCHING CURRENT	32	1.1 - 25 Amps	8	3 - 8 Amps
		[5 - 10 Amps]		
APPLICATION	25	Domestic hot water	5	Domestic hot water
	25	Space heat (air)	7	Space heat (air)
	23	Space heat (liquid)	3	Space heat (liquid)
	11	Pool/SPA	2	Pool/SPA

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4. TITLE AND SUBTITLE

INITIAL TEST RESULTS AND TEST PLAN FOR DIFFERENTIAL TEMPERATURE CONTROLLERS USED IN SOLAR ENERGY SYSTEMS

5. AUTHOR(S)

Joseph Greenberg

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
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U. S. Department of Energy
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Solar Buildings Technology Division
Washington, DC 20585

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The initial test results and procedures used to conduct tests on differential temperature controllers used in solar energy systems are discussed. These tests were performed on generally non-adjustable, non-display units and include the following functional tests conducted at ambient conditions: delta T "on" and "off"; recirculating freeze protection with and without auxiliary sensor; controller response to sensor sensitivity; storage high temperature limit; and pump "off" below 80 C. Controller sensitivity to line voltage variation tests were also conducted at ambient conditions and include: delta T "on" and "off" and recirculating freeze protection. The controller test fixture is also described along with the recommended use of decade resistance boxes to simulate thermistor inputs. An overall test plan is also included as an appendix to the report.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Differential temperature controllers; functional tests; sensors; solar energy; test plan; test procedures; thermistors; voltage fluctuation tests

13. AVAILABILITY

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